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Proceedings of the GEOLOGISTS' ASSOCIATION

THE GEOLOGICAL SURVEY OF COALFIELDS: A REPORT ON PROGRESS

By T. Eastwood, A.R.C.S., M.I.M.M., F.G.S.

(Presidential Address, delivered 7 March 1952)

SUMMARY.—Coal, Britain's most important mineral, is extracted mainly from the Coal Measures but some is obtained from older strata (Carboniferous Limestone Series of Scotland and Northern England and formerly from the Millstone Grit between Stainmoor and Derbyshire) and some from younger formations (Jurassic coals of Brora and NE. Yorkshire and Tertiary lignites of Bovey Tracey and North Kent).

The effects of foundation and cover-rocks, the transgression of the Coal Measures on to pre-Carboniferous rocks in the Midlands and the interruption of coal deposition 'islands' and 'peninsulas' are considered. The effects of unconformable cover and danger from water are commented on.

In addition the following subjects are outlined:

Mining plans, borings, and data for geological maps and the improvements in geological maps; identification and correlation of beds and belts of strata by lithological, palaeobotanical, palaeontological, and other aids, and the estimation of coal reserves.

INTRODUCTION

COAL is our most valuable mineral for on it depends nearly all products not only of national importance but also of our well-being as individuals. It has been the subject of geological, mining, metallurgical, chemical, commercial and political investigation, of Royal Commissions, many Acts of Parliament and innumerable regulations, and now it has been nationalised. Here we are mainly concerned with the geological aspect with, perhaps, a bias towards utility.

In common with most mineral deposits but particularly with those occurring in beds, it is essential that as complete a knowledge as possible should be obtained of the sequence and structure of the coal-bearing formation. If the sequence is known then we are well on the way to elucidating structure and while the converse is not always true to the same extent, structure, apart from anything else it may do, does provide clues with respect to possible rock-sequences.

There is little use in investigating structure and sequence unless the results can be portrayed in plan and elevation or, as we commonly say, on map and sections. A plan is the view of an object from above whereas the elevation is the side view. In some mineral deposits, such as occur in lodes or in very highly-inclined beds, the side view, which

is roughly, but only very roughly, at right-angles to the plane of the deposit, is almost as important as the plan. Naturally these documents are drawn to illustrate particular things while keeping these in their proper context. For instance, some mining plans are devoted to ventilation or to transport while others are confined to the occurrence of the mineral and its workings, just as there are topographical maps, road maps, rainfall maps, and so on. The distinction between a plan and a map is one of degree but in general the map, so to speak, takes a wider view than does a plan. In this country the Ordnance Survey, which produces some of the finest maps in the world, calls them maps if they are on a scale of 6in. to a mile or less, and plans when they are on a greater scale; thus we have 6in. to a mile, 1in. to a mile maps, and so on, and 25in. and 50in. to the mile plans; but, of course, this distinction is purely arbitrary.

Plans and sections are essential to all but the smallest of mining enterprises and have been in use from time immemorial. In metalliferous mining, plans of sorts were in use before the Christian era. It is uncertain when they were first used for coal, but, as the latter did not come into common use until about 200 years ago, colliery plans may be said to be relatively modern.

GENERAL CONSIDERATIONS

The bulk of the coal got in Britain comes from the Coal Measures though some is got from older and from younger rocks. In the latter category are the Jurassic coals locally of workable thickness and quality in north-east Yorkshire, and that still worked at Brora north of the Moray Firth; also there are the Tertiary coals or lignites such as occur at Bovey Tracey in Devonshire and locally in North Kent though these lignites are of little value as fuel. With respect to older strata, the tripartite division of the Carboniferous into Carboniferous Limestone, Millstone Grit and Coal Measures tends to conceal the fact that considerable quantities of coal exist and are worked in the Carboniferous Limestone Series of Scotland, where the Limestone or Edge Coals are sandwiched between an Upper and Lower Limestone Series, and in the limestone measures of Northern England. North of the Border and for many miles south of it, the Millstone Grit may be regarded as barren but coals come in about Stainmoor and are locally good enough to work as far south as North Staffordshire and Derbyshire.

In the same way the name Coal Measures may be misleading for, as a rule, the Upper Coal Measures are barren, or nearly so, except in the South Wales region. The name Productive Measures is often used for the grey strata lying between the Millstone Grit and the frequently red Upper Coal Measures; as the name implies, these carry the principal coals and is preferable to the older, but not always well defined, Lower and Middle Coal Measures which, in general, it

replaces. Whatever the age of the coal-bearing strata the problems are much the same and may be summarised as relating to sequence, structure and extent.

No general geological investigation of a coalfield can be regarded as complete that does not include a study of associated rocks, older and younger than the coal-bearing strata. The former may be in conformable sequence with the Coal Measures as in, amongst others, the coalfields of North Wales, Lancashire and Yorkshire, and include great thicknesses of Carboniferous Limestone and Millstone Grit. Structures affecting one of the series are likely to affect all members. On the other hand, where the Coal Measures rest on much older rocks, structures affecting these may not affect the coal series; moreover, the latter may at any stage in deposition impinge against islands or barriers of the older rocks. Mention may be made of the Midland Coalfields as examples of these phenomena. As these fields are approached from the north, Carboniferous Limestone and Millstone Grit fail; in Warwickshire, Productive Measures rest directly on Cambrian, and in South Staffordshire on Silurian strata. Millstone Grit and Carboniferous Limestone do not reappear in force until South Wales is reached. Both in Warwickshire and in South Staffordshire there is evidence that masses of these old rocks persisted as land of some sort while a considerable part of the Coal Measures was deposited. In the well-known 'Silurian-banks' of Staffordshire (Whitehead, T. H. and T. Eastwood, 1927), the Thick Coal and earlier seams end against such barriers whereas later higher coals pass uninterruptedly over the islands. Towards the southern end of that field the coals fail and eventually, near Rubery, Upper Coal Measures transgress on to Silurian rocks. In Warwickshire an 'island' has been postulated near Dosthill by G. Barrow (1919, p. 41), to account for espley rocks in the Etruria Marls composed of fragments of Stockingford Shales, and it is likely that other 'islands', if not 'peninsulas', persisted well into the sequence of the Productive Measures in the area farther south.

Commercial interest in the cover-rocks centres on two main aspects—presence or absence of coal and dangers of working. The recognition of large areas of red rocks as Upper Coal Measures instead of Permian, as at one time supposed, has had a considerable effect on exploration. Where the cover-strata are Upper Coal Measures and succeed the Productive Measures conformably, or nearly so there is a strong probability that the Productive Measures will continue beneath the newer strata for considerable distances, though the presence of 'islands', such as those of South Staffordshire, may be anticipated. This is especially the case if, as in the South Midlands, the cover-rocks include conglomerates and breccias with a high proportion of pebbles derived from rocks older than the Coal Measures, as in the case of the Clent Breccia, Corley Conglomerate, etc. While borings may reveal by chance the presence of such

interruptions, their location is as yet extremely speculative, though geophysical exploration may provide some clues as to their whereabouts.

Where the cover is unconformable, as in the Permian, in the Trias and in later strata, structures ante-dating the cover are also hidden and Coal Measures may be absent wholly or in part over wide areas on concealed anticlines. There are examples of these around many coalfields but the Eakring oilfield near Newark, described by G. M. Lees and A. H. Taitt (1946), provides an excellent one. Here elongated domes or anticlines, postulated by geologists and then roughed out by geophysical means, were revealed in exploratory and oil-development borings.

In concealed areas, where coal has not been entirely swept off, other problems arise. Both the Trias and the Permian are heavily watered and, as a rule, there is little or no impervious strata at the bases of these formations which may rest directly on Productive Measures. East of the Pennines, the Magnesian Limestone transgresses Coal Measures from Durham to Nottingham and, in the concealed coalfield, any uprise of the coal-bearing strata may bring coal workings in dangerous proximity to vast quantities of water. A detailed knowledge of structure is, therefore, essential in order that colliery officials may be forewarned.

Farther west, where Trias is the concealing medium, an added danger arises from the irregular base of that formation with the result that two factors must be considered: (a) any uprise of the Coal Measures, and (b) any marked downward irregularity of the base of the Trias where coal workings are approaching, or are likely to approach, that plane. It may be recalled that in the Cannock area of South Staffordshire, several miners lost their lives due to the collapse of thin basal clay-beds of the Trias by mining subsidence and consequent flooding. An account of the precautions taken are given by J. J. Staley (1946).

In the Kent Coalfield, there is a similar danger from the uneven transgression of Jurassic beds and here there may be no colour difference or red staining to warn of the proximity of the newer strata.

Though not affecting a concealed coalfield, the recent disaster at Knockshinnoch, due to the irruption of a peat-bog, emphasises the need for close co-operation between geologists and mining men. In undersea operations the rule of 50 fathoms of cover between the seam being worked and the sea-bottom provides a good margin of safety; before thickness of cover was insisted upon, collapse of the roof brought in the sea at Moss Bay, Workington, in 1837 (Eastwood, T., 1931, p. 171).

Sufficient has been said to justify study of the strata above and below the Coal Measures in coalfield investigations.

MAPS AND MINING PLANS

The normal scale for coalfield investigation is now the 6in. to the mile map to which we are so accustomed that few people realise that it was not available to any considerable extent until 1860-70, when it was used for the Scottish and Northern England coalfields. By that time most of the other coalfields had been surveyed on the one-inch scale and the Geological Survey then adopted the regrettable practice of assuming that, when once surveyed, the job was finished. These one-inch maps were excellent productions for their time and I have often marvelled at their accuracy, but even supported as they were by collections of horizontal and vertical sections and by memoirs, they could not be regarded otherwise than as very general guides to coalfield work and exploration. Here I may remark that mapping on the one-inch scale survived until the 1890's; most but not all of the modern one-inch maps, however, are based on 6in. survey.

The Geological Survey owes much to outside help and stimulus (see Flett, J. S., 1937). With respect to maps we may note the excellent work of Sopwith in the Forest of Dean (1841). He not only produced plans and maps on the scale of 10in. and 2½in. to the mile but also a model of that field with removable beds (of wood). He did even greater work elsewhere in that, by his efforts, the standard of colliery surveying, the keeping of records and of mining practice in general, was raised very considerably. Another helper of the same pattern was Wm. Saunders who produced maps of approximately 4in. to the mile of the Bristol Coalfield in 1862. These were used by Anstie (1873) for the Coal Commission then sitting, and were an improvement on the Survey maps of 1842. That Commission called for more geologists for the Survey and for better maps but its efforts in that direction were later largely defeated by the lack of vision and the cheese-paring economy of departmental heads.

Revision of coalfield-areas, mapped on the one-inch scale, was begun on the 6in. scale about 1890 in South Wales to replace the rather sketchy survey of 1840. This spread fairly quickly considering the small staff and funds available but not enough to satisfy the Coal Commission of 1904 which again demanded more data.

The notion of a coalfield-survey being completed still held until recently when my efforts led, as I believe, to the saner view that active exploitation in any field should go hand-in-hand with geological work and that no survey should be regarded as complete until a field is virtually exhausted.

As far as ordinary field work is concerned, coalfield-practice follows that of other areas in that all outcrops and features and variations in topography are used to the fullest extent. This work gives the general sequence and structure which has to be supplemented by mining data based on examination of plans, sections, borings, visits underground, and so on. In my opinion it is unwise to skip or skimp

any of this work, for plans, at first sight of little value or mere copies of others, may contain some scraps of vital information not given elsewhere. This leads us to the consideration of mining plans in general.

As stated in the introduction, plans of metal mines are of considerable antiquity. A papyrus, preserved in Turin, shows workings of an Egyptian goldmine of about 1400 B.C. and here it may be noted that land surveying was first practised in Egypt because, owing to the annual flooding of the Nile, landmarks to property were often swept away or buried in mud. Bennett Brough (1904) notes that in Britain some attempt at mine-plans was made in the Mendip lead area about 1480 and instructions on the making of mine-surveys were published by Thomas Houghton in 1681 for Derbyshire lead miners, by Wm. Price in 1778 for Cornish miners, and by Thomas Fenwick in 1804 for the colliers of Newcastle. Plans had been in use in these places, of course, before these dates.

Some of the old plans are more conspicuous for their beautiful ornament than for surveying but they often contain some useful information if they can be located with respect to present surface; for such directions as 'Ye roade to ye moore', as in Cumberland, or small bits of canal, as in South Staffordshire, are often the only topographical guides.

In the early days colliery plans were of all sorts of scales, even for the same colliery, but Coal Mines Regulation Acts of 1887 and 1896 prescribed that they should show an accurate plan of the workings, be not more than three months out of date, should indicate general dip, give a section of the strata passed through in the shaft, or, if that be not practicable, state the depth of the shaft and give sections of the seams, show position and throw of faults—all this information had to be shown on a scale not less than 25in. to a mile and related to surface detail for correct orientation.

Many mining disasters are attributable to faulty surveying and recording, but it was not until recently that mine surveyors received much encouragement in the way of pay or status. An Act in 1912 demanded better training and an examination of the surveyor. It also required plans to be of a scale not less than 40in. to the mile for collieries opened after that date and the insertion on them of spot-levels related to Ordnance Datum.

Previous to this date, the altitude of workings had to be estimated by the geologist by any means available. Horizontal sections by the colliery people are not numerous but there were occasional notes of the depths of workings below certain openings (though the location of these often proves difficult today) and the strike might be ascertained by the shape of the workings, particularly if a pair of roads at the limit of the workings followed roughly parallel but sinuous courses indicative of water-level.

Although contours have been in common use on topographical

maps for well over fifty years, their employment on colliery plans is very recent; yet such collated information is vastly more useful than scattered spot-levels.

From early efforts on the part of the geologist, such as Walcot Gibson (1913) and Eastwood (1923) dependant on the few spot-levels or approximately known altitudes available thirty or forty years ago, the practice has grown of showing contours of the principal seams on the 6in. geological maps and of the preparation of isopachytes of seams, or of the strata intervening between them, on maps included in various publications (see, for example, Edwards, W., 1940 and Mitchell, G. H., 1945). Indeed, in general, the public is much more 'contour-conscious' than formerly.

Another Act of Parliament of considerable importance is that of 1926 which gives the government geologist the right of access to workings and plans, and permits examination of borings (which, moreover, must be notified in advance to the Survey if expected to exceed 100ft. in depth). Previous to 1926 no such rights existed and the work depended on good will. Apart from my own experience, the records of the Geological Survey indicate that there was extremely good measure of such good will, though in most coalfields there were odd owners or managers who refused access and, incidentally, often suffered in the long run from their lack of co-operation. As a rule, when the geologist proved that he could be of some real use to the mining man, the attitude of the latter soon passed from slightly amused tolerance to respect. We have yet to see what nationalisation of the mines will do, but it should prove a golden opportunity for the wholesale co-operation of the geologist and the colliery surveyors and planning officials in all exploration and development work. Of necessity this will depend largely on geological maps and records.

Here, perhaps, I may be allowed a personal note. Until after the First World War, records of borings collected by the Survey were merely assembled in county boxes, most were but poorly sited and few had correct altitudes. Transference to Cumberland with its numerous borings, particularly for iron ore, drove me to registration of localities on six-inch maps and an adequate filing system. This system, which enables any boring to be found in a few minutes, has now been adopted for the Survey collection including water supply borings. In those early days the 'powers that be' were reluctant to supply any maps except for actual use in the field and clean copying. Mining data had to be inserted as well as could be managed on field slips often already overcrowded with notes. The issue of very poor quality paper to the Ordnance Survey provided a long-sought opportunity; I pointed out that such maps could not survive field work in the Cumbrian climate but they need not be wasted for they would serve for mining data; afterwards it was merely a matter of precedence until the use of copies devoted entirely to mining became standard practice.

BORINGS

Some mention has already been made of boring and, while it is recognised that this is not the place to deal with the history or technique of boring, some remarks thereon may be permissible since boring and records of borings are so important in coalfield work.

Whenever the mining or quarrying man lost the deposit in which he was interested, he made holes in search of it; the holes were made as small as could be used by a thin man or holes were drilled by elongated chisels—in other words by boring. The making of any small diameter holes in any kind of material, ranging from apples to stone or metal, depends on the same principles—either percussion cuts as in chiselling, scraping cuts as in the use of auger-bits or twist drills, both of which furnish fragments of the material, or a rotary cutting implement like the apple corer which gives a cylindrical block of the cut material. It is obvious that direct percussion becomes ineffective as the length of the chisel-shank is increased so that, beyond a few feet, an up and down jumping motion has to be introduced. In exploratory, as opposed to blast-hole drilling, this is usually achieved by attaching a rope to the chisel and passing the rope over a pulley in a headstock or derrick and then applying a 'pull-and-let-go' motion either by hand or by the use of a powered crank. This method has been in use since very early days and for coal at least 200 years. The scraping rotary cutter, giving rapid penetration, is used extensively in oil-drilling but the purpose for which a boring is made differs considerably where the mineral is oil from that required for solid minerals. In the former, the object is to find a belt of rock saturated with oil and provide an outlet to the surface for it; in other words, to work it. In the latter, particularly in bedded deposits such as coal, as much information as possible is required of the bed and of its roof and floor before it can be worked. The taking of a core of a seam, therefore, may be regarded as essential, and, since the position of coals cannot be forecast with accuracy (or there would be no need for boring), it is desirable that coring should be done throughout the coal-bearing strata unless the clients are certain as to the horizons already penetrated and to the position of those to be cut.

Core-boring has been in use here for about a century using first a serrated pipe like an apple corer, then chilled shot dropped down the hole (which operates like a broken ball-race in cutting its mounting) and then to a pipe armoured at the bottom end with diamonds. The preservation of the core in the core-barrel above the cutting edge, the support of the sides of the hole by steel casing-pipe or by plastering with mud, as in mud flush methods, and other technical modifications have received much attention and are still matters of research, but three things are essential for a high percentage of core-recovery in such a brittle material as coal, particularly at depth; these are a high grade, sweetly-running drill, a craftsman drill-artist in charge,

and suitable lithology; and all three must be operative at the same time.

It has always been a mystery to me why people should spend large sums of money on boring and then waste the results by not taking proper care of the cores until at least they have been measured and recorded in detail. Often in the cases where a geologist was permitted and even invited to examine cores, they would not be in correct order, but often badly mixed up, with depths unmarked and, therefore, impossible to verify. Some improvement has been made in these matters of late but much remains to be done. Occasionally secrecy has led to the waste of results as, for example, in the Kent Coalfield as a whole.

IDENTIFICATION AND CORRELATION

The Coal Measures, often with coals at intervals of 100 ft. or so, are over 5000 ft. thick in Lancashire and in South Wales but thinner in other fields. The identification of seams is, therefore, a matter of great importance, especially in tracts separated by faults. In some cases, owing to mistaken identity, a coal has been believed to lie near the bottom of the coal-bearing strata, whereas, in reality, its position in the sequence was hundreds of feet higher; such instances are not merely of academic interest, for an area may be abandoned while still capable of yielding millions of tons of coal.

Lithology.—Colliers can often distinguish between seams that appear alike to less skilled observers or ‘handlers’, but either their skill fails or the character of the seam changes if the localities are more than a few miles apart. Attention is also paid to roof and floor-measures and to partings but, as a rule, mining men have largely ignored details of intervening strata apart from thickness. The geologist, on the other hand, pays considerable attention to these measures because, at outcrop, they are more often seen than the coals; his basis of correlation, in the first place, is lithological and he attempts to correlate belts of strata *he has seen* at surface with those *recorded* by dead-and-gone non-geological observers of shafts, sinkings and borings. ‘Playing patience’ with plotted sections of such records is still the mainstay of the coalfield geologists and the use of vertical sections is obvious to all.

Some lithological characters noted by the geologist will persist for miles while others are extremely local, and it is art rather than science at times that decides the question of correlation. Sandstones are notoriously variable both as to their incidence and to their character, yet used with care they are valuable indicators of horizon. As examples we may quote the Farewell Rock of South Wales, the Rough Rock of Lancashire and Yorkshire, and the Elland Flags, as reasonably constant over wide areas; of sandstones locally of value but exchanging characters, Cumberland provides a case; here the

Four Foot Rock, near the base of the Coal Measures, is coarse and pebbly in the southern part of the field while one above the Six-quarters Coal, 240ft. higher, is sugary in appearance; traced northwards, the Four Foot Rock becomes sugary and then fine-grained before it disappears and its coarse characters are taken on by the Six-quarters Rock. Ankerite cement—which on exposure becomes rusty—may characterise certain sandstones and peculiar fireclays, shales, mudstones and ironstones; banding of coals may mark other horizons, but since similar rock types may recur at intervals in the sequence, often in rhythmic cycles, lithology alone will not always suffice. Occasionally a defect in a seam may be utilised for correlation as, for example, the prevalence of washouts in the Middleton Main, or a defect in the coal itself.

Chemical composition.—The chemical composition of coals, of fireclays and of other bands, proves a useful aid in correlation provided the analyses are from fairly evenly dispersed localities, though analyses of coals not related to the particular bands that constitute most seams, may be very misleading. For instance the dull, hard, upper part of a seam, present at many pits, may be cut out by pene-contemporaneous erosion in a certain direction while the bright lower part may remain, or even thicken, in the same direction. The analysis of coal, sub-section by sub-section and following a standard routine of analysis, as practised by Fuel Research of the Department of Scientific and Industrial Research and now of the Coal Board, is a great advance on the older methods. Apart from inherent changes in composition laterally, attention may be drawn to South Wales where the coals change from the bituminous class in the east to anthracite in the west, and the incidence of these changes in the same seams at various levels—information which has been used by Dr. F. M. Trotter and by Prof. O. T. Jones in recent discussions on anthracitisation.

Fossils as a whole.—From very early days mining people and geologists have noted the presence of fossils in strata associated with coals and some such occurrences have for long been regarded as diagnostic of certain horizons as, for example, goniatites and pecten shells with the 'Mountain Mines' of North-east Lancashire. When the fossils are allied to some striking lithological character their recognition is rendered easier as, for example, the soapy blue shales over the hard limy 'cank' of the Mansfield Marine Band. In fact in many cases it is not the species or even the genera of the shells, plants, or fishes but their association with a peculiar sequence of lithology that provides the clue.

Fossil plants.—As may be expected, fossil plants are widespread in coal-bearing strata. Their prevalence at certain horizons often furnishes a good but strictly local horizon-marker, as, for example, in the partings of the composite Main Band of Cumberland. In South

Wales very extensive collections were made by D. Davies (1921) in the study of plant-ecology and T. H. Rowlands (1925) dealt with plant-frequencies in the Pennant Series, but the most notable advances, following on the detailed work of Kidston, Arber and Crookall, were made there by Dr. Emily Dix (1934) who proposed a floral zonal classification based on that of continental workers. These and the plant-zones of other workers, however, are too large to be other than of very broad use in stratigraphy.

Many coals, particularly in the hard dull bands, contain an abundance of spores and various investigators have attempted to use them as horizon-markers. Some real success might attend these efforts if the workers were content with a slow regular expanse of test-samples instead of attempting relatively wide correlations on slight data. In this country Dr. A. Raistrick was the pioneer in the use of microspores with papers dating from 1933. He took channel-samples each weighing between 3 lbs. and 6 lbs., according to the thickness of the seam, ground the chippings to pass through a 10-mesh sieve, then quartered this to give about 4 ozs., which was pounded and frequently shaken on a 50–60-mesh screen till all passed through. This dust was oxidised with Schultz solution (nitric acid with a few crystals of potassium chlorate added) and cleaned up with a 10 per cent aqueous solution of potassium hydrate before mounting in glycerine jelly. Dr. Raistrick claims to recognise several groups of microspores, indicated by letters, and subgroups, indicated by numerals. Some of these are present in most coals while others are regarded as accessory. Both, but particularly the former, are used in the preparation of spore-diagrams made up of adjoining rectangles whose heights are proportionate to the percentage of that particular type of spore counted on a slide which may carry 600–700 microspores. The method was carried further by the officers of Fuel Research who dealt with a seam by subsections as for coal-analysis. Dr. J. O'N. Millott (1938–9, for example, in dealing with such subsections, pp. 325–6) records that the presence or absence of dull coal, which is rich in A-type, has an important bearing, as one would expect, on the assemblage diagram, and that, where dull coal is absent, then D₁-type generally predominates. This spore-diagram method of correlation has been received with acclamation by some geologists but the fact remains that, in many cases, the spore diagrams show more variations laterally in seams of which there is no question as to correct identification than do those of seams separated by considerable thicknesses of strata. In other words, the method falls far short of the result claimed for it. Moreover, Dr. Crookall, a trained palaeobotanist, expresses grave doubts, to say the least, as to the validity of the spore-groups (Crookall, R. and L. S. O. Morris, 1952).

Non-marine lamellibranchs.—These shells, commonly and collectively known as 'mussels', are widespread in the Coal Measures; they

may be scattered through mudstones or shales, closely aggregated into mussel-bands, of which there are examples in most coalfields, or preserved in ironstones, as above the King Mine of North Staffordshire and the Arley of North-east Lancashire. Quite a number of these shell-beds have attracted the notice of shaft-sinkers and colliery workers though the same horizon with scattered mussels passes unnoticed.

It is now about half a century since Wheelton Hind, working in North Staffordshire, used mussels in a zonal scheme beginning with (1) *Carbonicola robusta* at the base, followed by (2) *Anthracomya williamsoni*, (3) *A. adamsi*, (4) *A. wardi*, (5) *A. phillipsi* and (6) *A. calcifera*; the last two characterise the Upper Coal Measures comprising Etruria Marls, Newcastle Sandstone and Keele Group.

This advance was not followed up for many years owing largely to the chaotic state of the classification of the mussels and I remember the disgust I felt in my early days with the Geological Survey, after making a collection of mussels from the roof of the Thick Coal at Newdigate Colliery, Warwickshire, only to be informed by the Palaeontologist of that date, that they were of no value whatever. In fact it was not until Dr. A. E. Trueman (now Sir Arthur) and his co-workers (1927-47) began to set the 'house of mussels' in order that the work, begun by W. Hind (1896), could be carried forward to the present scheme. Even so, though certain bands, characterised by a particular shell or shell-assemblage, are useful in relatively local correlations, the zonal scheme is still too wide-meshed to be other than of general use; in other words mussels permit belts of strata to be correlated but usually fail as marker-bands unless accompanied by a rock-type peculiar to the horizon. From below upwards the Trueman zonal sequence is as follows: (1) *Anthraconaia lenisulcata*, (2) *Carbonicola communis*, (3) *A. modiolaris*, (4) *A. pulchra* and *Anthracosia similis*, (5) *Anthraconauta phillipsi* and *A. tenuis*; of these, zones 1-4 are grouped by him as Ammanian and as Morganian; the two latter refer to the Upper Coal Measures.

It is noteworthy, perhaps, that, taking the coalfields as a whole, the bulk of the workable seams lie in the zones of *A. modiolaris* and Lower *similis-pulchra*.

Marine fossils.—Although marine shells were known from several coalfields a hundred years ago, their stratigraphical value was not really appreciated until about the end of the nineteenth century. By then, one or two horizons were known in the major coalfields, one usually low down in the sequence and the other towards the top of the coal-bearing strata. The latter came into prominence largely through the work of Walcot Gibson (1913) in explorations to prove the concealed York-Nottingham-Derby Coalfield where the Mansfield Marine Band provided a useful marker; in the type locality of Mansfield, this lies about 650ft. above the much-prized Top Hard

Coal. Since then this famous band has been correlated with Skipseys Marine Band of Scotland and the Cefn Coed Marine Band of South Wales, as well as others in many intermediate fields, giving a range of over 400 miles (or virtually the length and breadth of the country). Search for the Mansfield has led to the finding of others—with some inevitable mis-correlation—and recent work, such as that of Edwards and Stubblefield (1948), has almost led to a plethora of marine bands and quasi-marine bands. In the latter category I would place those with *Lingula* only, for I believe that this brachiopod could tolerate brackish water, whereas in a true marine band the fauna would include goniatites, productids, ribbed lamellibranchs and so on. A marine band may vary in thickness from a mere film to over 20ft. This happens in places with the Mansfield Marine Band, and finding it may be a matter of luck, but what may be accomplished by co-operation between the Survey and coalfield personnel in an area with many outcrop coal workings and several recent borings, is indicated by the ten marker-bands established in Nottinghamshire and Derby by Edwards in 1948 and now being followed northwards by Goossens (*in litt.*) and others.

Other fossils.—The scales of fish, often preserved in canneloid shales, are locally of value in correlation as are the remains of crustaceans, insects and so on, and even the lowly worm *Spirorbis* which characterises certain thin bands of porcellaneous limestone in the Upper Coal Measures. These limestones range from Cumberland and Lancashire to the Midlands and from low in the Etruria Marls, or even from upper Productive Measures to high in the Keele Group but cannot be regarded, save locally, as first-class indices of horizon.

Other aids.—In the cover-rocks a study of the heavy minerals may be of some help but, in order to obtain optimum results, calibration by one or more borings, where cores are available for sampling at intervals of 50 ft. or so from the base or some recognisable horizon, is desirable. Some of the sandstones in the Productive Measures may repay petrological study though this branch appears to have been neglected.

In oilfield exploration great use is made of geophysics both in the study of the electrical logs of borings and in preliminary surveys. With respect to the former no such means equal that provided by a good core but the latter field promises economy of time and money in the exploration of concealed areas. For example, Coal Measures affected by, say, trough-faults may pass under Trias showing no such faults. Usually a geophysical survey will at least give some indication of the trough and allow borings to be sited to give optimum results. Anticlinal structures, such as those in the Newark area, have already been noted and a further possibility of using geophysics appears to be in the investigation of the heavily watered, basal Trias, though this might be complicated by locally perched water-tables due to faulting.

ESTIMATION OF COAL RESERVES

Considerable stress has been laid on identification and correlation and this is a matter which has a direct effect on the estimation of coal reserves. It is relatively easy to calculate the reserves of coal in, say, a royalty area of ten square miles where there are workings, shaft sections and borings. It is less easy to estimate the reserves of a coalfield for there it is likely that unknown or little-known areas will balance known areas.

Reserves, estimated by or for the Royal Commissions of about 1870 and 1904, were based on the acreage of seams a foot or more thick shown on the one-inch geological maps or on the presence of such seams, or the supposed presence of them, in such areas to depths of 4000 ft. in some cases and 6000 ft. in others. As a rule the estimates were made not on individual seams but on the assumed aggregate thickness of the coals in a large belt of strata. From the totals allowances were, of course, made for coal already worked and for that which was unlikely to be worked on account of surface support required or because of faults, and so on. The grand totals in each case were large. Various individuals have also made estimates much on the same lines.

More recently reserves for individual coalfields have been made in the form of Regional Survey Reports to the Minister of Fuel (1945–6). Most of these were based on data supplied for the computation of the compensation to be paid to the then royalty owners when the coal in the ground was nationalised. This method leaves much to be desired in that compensation was to be paid on the number of years a royalty could be expected to accrue but, as in most compounding schemes with a limit on the number of years to be taken into account, the estimate of coal available is less than it should be. These estimates did, however, draw attention to the fact that certain coalfield areas were rapidly approaching exhaustion, for example, Lanarkshire, parts of Lancashire, and the Forest of Dean. Moreover, it became apparent that reserves of particular coals of coking quality were being unduly depleted, as in Durham, by misuse for other purposes.

Any objections to the methods employed were overruled largely on the plea of expediency. There is still time, however, to make amends and the scheme I then proposed is just as applicable now. In brief, the scheme is that the coalfield basis of calculation should be on special maps on the one-inch scale based on six-inch data; the outcrop of each coal seam should be shown—as solid lines where the crop is known within 20 yds., as broken lines where believed to be within 100 yds. and as dash-blank-dash lines with line and gap of equal length for other cases; each seam should have its special map showing not only the crop but also known large faults, washouts, and the like, with contours at O.D. and at each 1000 to 4000 ft. O.D.; principal

shafts and borings with depths to and thickness of the seam, isopachytes of the seam where possible, lines of serious splitting with, if necessary, additional maps for the split-off portions; lines to indicate where a seam has become worthless on account of dirt bands, undue splitting and the like, or of thickness so diminished as to be unworkable in that area.

The preparation by the geologist of maps of this nature entails accurate correlation; if accuracy is in doubt it should be indicated so that the user knows the quality.

In some cases it is possible for the geologist to indicate areas already exhausted but usually that is a matter for the colliery surveyors who now generally have maps on 6 in. scale showing worked-out areas. It is then the turn of the chemist who, from analyses of the coals at marked sites, will give lines of equal quality and so on.

From these maps computations of reserves would be of real value because the quality of the data would be obvious at a glance, and in areas of doubt or of little information, steps could be taken to amend the defects by any of the people concerned—geologist, chemist, colliery surveyor or coalfield planning authority.

CONCLUSIONS

There has been a considerable improvement in the maps of coalfields and in my opinion the modern six-inch map, with its underground contours and its generalised vertical section, shows as great an advance over its predecessors of forty or fifty years ago as did these over the one-inch maps of the period 1850.

Some of the improvement must be attributed to better mining plans of the last thirty years.

The Coal Measures may now be zoned by the use of fossil plants, 'mussels' and marine shells, but these zones are not yet fine enough for close correlation and a combination of any one or all of these means, with a detailed knowledge of lithology, will give much better results than reliance on fossils alone.

The analyses of coals, subsection by subsection of the bands as practised by Fuel Research, is a great advance on previous methods.

Methods of boring have improved and good cores are to be preferred to any other type of boring.

Geophysical methods offer scope for exploration of concealed areas preliminary to boring in connection with structures and with heavily watered strata.

Reserves of coal on a large scale, i.e. other than on a purely local basis, should be done from individual seam-maps prepared by the combined efforts of geologists and mining men. Individual seam-maps, showing a summary of all relevant data, draw attention to gaps in knowledge.

There is still plenty of scope for geological work in the coalfields,

both for the Geological Survey and for other geologists, but detailed investigation is to be preferred to expansive application of methods on insufficient data and sketchy mapping.

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AMMONITES FROM THE UPPER OXFORD CLAY AT STANGATE HILL, NEAR HUNTINGDON

By W. J. Arkell, F.R.S., and E. L. Holt

[Received 23 July 1951]

NOTE.—The following is written by W. J. Arkell from the study of a series of collections made at Stangate Hill, the first by Lieutenant Edward L. Holt of the U.S. Army, who measured and drew attention to the cutting in 1943. This account incorporates information from his notes.

AT Stangate Hill, one mile north of Alconbury Hill and six miles NW. of Huntingdon, when the Great North Road was widened shortly before the 1939 war, a cutting exposed Chalky Boulder Clay resting on Oxford Clay.

Lieutenant Edward L. Holt, stationed near by, measured and described the cutting in the early part of 1943. He collected about 236 ammonites, which he submitted to the Sedgwick Museum. They were sent to me by Mr. A. G. Brighton for determination in April 1943, after which a representative collection of about fifty specimens was returned to Lt. Holt, who took them to America. The rest he presented to the Sedgwick Museum. They are well-preserved pyritic casts, and constitute an interesting assemblage of the *mariae* Zone of the Upper Oxford Clay.

After moving to Cambridge in 1947, I collected several times at the cutting, assisted by Prof. W. B. R. King, Mr. A. G. Brighton, Mr. A. E. Gunther and others, and altogether more than 400 ammonites were obtained during 1947–50. The sides and bottom of the cutting still yield ammonites at every visit, but comparison of the new collections with Lt. Holt's shows that few further novelties can be expected. The total number of specimens now collected is 646, belonging to at least twenty species, and it seems desirable that they should be recorded.

There are also belemnites (*Hibolites hastatus*), rhynchonellids and a few small gastropods and lamellibranchs. *Gryphaea dilatata* (J. Sow.) ranges throughout the section, and there is much selenite.

Stangate Hill is at the northern edge of a projection of the Boulder Clay plateau, the top of which is here about 155 ft. O.D. The exposures lie between the 100-ft. and 50-ft. contours as shown on the one-inch Ordnance Survey map (Sheet 134). According to Lt. Holt's measurements, made with a Brunton compass, 23 ft. of beds are exposed, of which 20 ft. is undisturbed Oxford Clay and 3 ft. Boulder Clay.

Small pyritised ammonites abound throughout the Oxford Clay and here and there are concentrated at certain levels, but even in

1943 Lt. Holt found it 'extremely difficult to locate definite fossil zones as the face of the cut is considerably weathered and the road-grader has scattered the material on the bottom', and, it may be added, because of the very oblique angle of the section.

The following is a list of my determinations, with the numbers of specimens. Owing to the small size of most of the material, specific distinction of some of the smooth Oppelliidae and, above all, of the majority of the Cardioceratidae, is impossible. The numbers against these, therefore, give only a general idea of their relative abundance. It is noteworthy, however, that 574 specimens, or eighty-nine per cent of the total, are Cardioceratidae belonging to the subgenera *Scarburgiceras* and *Pavloviceras*.

LIST OF THE AMMONITES

(with numbers of specimens collected)

<i>?Lissoceras rollieri</i> (de Loriol)	}	17
<i>Hecticoceras</i> (<i>Sublunuloceras</i>) <i>bonarellii</i> de Loriol		
" (<i>Brightia</i>) <i>svevum</i> Bonarelli		
<i>Taramelliceras</i> (<i>Proscaphites</i>) <i>richei</i> (de Loriol)		9
" " <i>episcopale</i> (de Loriol)		2
" " cf. <i>heimi</i> (de Loriol)		4
" " cf. <i>coquandi</i> Maire		2
<i>Creniceras renggeri</i> (Oppel)		7
<i>Scaphitodites scaphitoides</i> (Coquand)		8
<i>Grossouvria miranda</i> (de Loriol)		3
<i>Perisphinctes</i> (<i>Properisphinctes</i>) <i>bernensis</i> de Loriol		2
" " aff. <i>latilinguatus</i> Noetling		2
" (<i>Alligaticeras</i>) cf. <i>nikitini</i> Par. and Bonarelli		1
<i>Euspidoceras babeanum</i> (d'Orb.) var. <i>subcostatum</i> Spath		3
<i>Peltoceras</i> (<i>Peltoceratoides</i>) cf. <i>athletoides</i> Lahusen		11
" (<i>Parawedekindia</i> ?) sp. indet.		1
<i>Quenstedtoceras</i> (<i>Pavloviceras</i>) <i>mariae</i> (d'Orb.)	}	60
" " <i>omphaloides</i> (J. Sow.)		
" " cf. <i>williamsoni</i> Buckman		
" " sp. or spp. indet.		
<i>Cardioceras</i> (<i>Scarburgiceras</i>) <i>scarburgense</i> (Young and Bird)	}	93
" " var. <i>crassa</i> Spath		
" " var. <i>transitoria</i> Spath		
<i>Cardioceras</i> (<i>Scarburgiceras</i>) <i>praecordatum</i> R. Douvillé	}	20
" (=douvilléi Maire = <i>praemartini</i> Spath)		
<i>Cardioceras</i> (<i>Scarburgiceras</i>) <i>praecordatum</i> var. <i>stricta</i> Maire... (= <i>extremis</i> Spath), and other vars.		
Unsorted Cardioceratidae (nuclei and fragments), all <i>Scarburgiceras</i> and <i>Pavloviceras</i>		401
Total		646

CONCLUSIONS AS TO GEOLOGICAL AGE

1. The assemblage is typical of the *mariae* Zone (Lower Oxfordian).

2. There is no specimen indicative of either the *lamberti* Zone below or the *cordatum* Zone above.

3. The abundance of both *Cardioceras scarburgense* and *C. praecordatum* indicates the middle part of the *mariae* Zone.

4. The abundance of *C. scarburgense* points to a date earlier than anything exposed at Purton pit (Arkell, W. J., 1941).

5. The abundance of *C. praecordatum* and the presence of *Scaphitodites*, combined with the relative scarcity of *Taramelliceras* and *Creniceras* and the absence of *Quenstedtoceras woodhamense*, point to a date later than anything exposed at Woodham pit (Arkell, W. J., 1939).

6. The nearest comparison is with Warboys pit (Spath, L. F., 1939), which is only seven miles to the east, and mainly with beds 1-3; i.e., the lower half of the middle *mariae* Zone.

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THE INFLUENCE OF ROCK STRUCTURES ON COAST-LINE AND CLIFF DEVELOPMENT AROUND TINTAGEL, NORTH CORNWALL

By Gilbert Wilson, Ph.D., F.G.S.

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ABSTRACT.—The paper deals with the morphology of the stretch of coast between Boscastle and the Treligga Cliffs in North Cornwall. The prevalent cliff-type is slope-over-wall, either hog's-back or bevelled as defined by Miss Arber (1949). Flat-topped cliffs are less common. It is considered that geological structures—bedding, jointing, faulting and, to a lesser extent, rock-type—have not only had considerable influence on the shape of the cliffs, but have also guided the marine attack on the coast. The evolution of most of the coast features, when seen in plan or profile, has been controlled by the local geological structure. The southern stretch of the coast is sub-parallel to seaward-dipping normal faults which have been stripped of their hanging-walls. Such a cliff-line is dominantly a fault-line scarp which has suffered slight retrogression.

1. INTRODUCTION

THE control of coastal morphology by the lithology of the rocks exposed to wave action has long been recognised by workers in North Cornwall. Thus Dewey (1914), in his description of this region, written preparatory to the Association's excursion to the district, stated (p. 155): 'The varying degrees of hardness of the rocks, which play only minor parts in producing the topography of the inland localities, are the main cause of the coast scenery. When the rocks are exposed to the violence of the sea, the soft killas is rapidly destroyed and washed away and wide bays result; but the sills and lava offer resistant masses which protrude into the sea as great headlands. . . .' Dewey lists among these promontories those of Trevoze, Stepper, Com, Varley Head and Pentire, ' . . . a towering mass of pillow lava with vertical cliffs rising majestically from the sea to a height of nearly 300ft.'

The active erosion that this passage suggests is now disputed by more recent workers. Thus Balchin (1946, p. 341) considered that

PLATE 1



there had been 'small change in the morphology of the area throughout later Pleistocene and Recent time: both sub-aerial and submarine denudation are alike in this respect . . . the location of the coastline has probably altered but little even if the detailed morphology has been subject to modification'. This statement is contained in a paper in which the morphology of North Cornwall was discussed from a regional standpoint. In the present article, however, it is the local modifications of the coast that are considered.

In many localities in the area, it has been observed that active erosion is proceeding along certain privileged paths which are structurally controlled. Such paths, in the case of flat or gently dipping structural planes of weakness in the rocks, are important only when the level of the sea happens to agree with that of the structural feature—literally a case of coincidence—and it is only rarely that such features are of much significance. Steeply inclined planes of weakness are, however, important over a big range of sea-level. They are paths of easy attack on the coast whether the waves break at 50 or 100 ft. above, or 50 or 100 ft. below the present tidal range. It is, therefore, reasonable to assume that the same relationship, which is seen today between the planes of weakness and marine erosional activity, also held in the past when the sea-level was different. It is on the basis of this assumption that the accompanying thesis has been developed.

The section of coastline discussed in this paper runs from Pentaragon and Boscastle in the north, to Backways Cove and the Treligga Cliffs in the south (Plate 1), a stretch of about six miles. From Boscastle to Tintagel the coast trends approximately S.60°W., from Tintagel to Backways Cove the trend is a few degrees west of south. Except for the embayment of the Trebarwith Strand beach, the latter section presents a much smoother plan than does the more crenulated strip between Tintagel and Boscastle. The cliffs are cut into the 300–430-ft. Trevena Platform of Pliocene age described by Balchin (1937, 1946), and in many places drop sheer from the platform to below sea-level. The number of routes by which one can reach the sea, is distinctly limited. Over much of the coast the cliffs show a *slope-over-wall* form (Whitaker, W., 1909), in which a vertical drop lies below a grassy slope which may be curved (convex upwards) thus forming a *bevelled cliff*, or may be a uniformly inclined surface yielding a *hog's-back*. The origin of these forms, which will be considered later, has been discussed by Balchin (1946) and Miss M. A. Arber (1949). Similar forms have been described from the Devonshire coast by E. A. N. Arber in 1911, and from Wales by Challinor (1931). Recently Cotton (1951) has proposed a two-cycle process, in which glacial control of sea-level plays a prominent part, for the evolution of the *slope-over-wall* cliffs of South-west England. The Cornish coast and other aspects of the geomorphology of South-west England have also been studied by Professor André Guilcher

of Nancy (1949, 1950), who compares the various features observed with those seen in Armorica.

The present writer, during periods of investigation of the tectonics of the Tintagel area (Wilson, G., 1951), became more and more impressed by the importance of structural features in influencing the local evolution of the coast and by the comparatively minor rôle of lithology. In the pages which follow, the part played by structures in the rocks and the manner in which they control the cliff-morphology, is discussed, and an endeavour is made to picture the principles of wave-attack on this picturesque piece of coastline.

The writer wishes to thank Professor H. H. Read for suggestions made during the writing of this paper, and also to express his gratitude to Mr. G. S. Sweeting who gave much helpful advice and constructive criticism. The map (Plate 1) has been reproduced from Wilson (1951) by kind permission of the Council of the Geological Society of London, to whom thanks are also tendered for the use of the original block.

2. GEOLOGICAL STRUCTURE

The current interpretation of the rock-structure in the Tintagel area was formulated by Dewey (1909) and was later summarised by him in 1914 and 1935. Recent investigations have shown, however, that the tectonic history of the area was more complicated than originally believed (Wilson, G., 1951). As Dewey so convincingly demonstrated, the coastal strip from Trebarwith Strand to Smith's Cliff is built up of overthrust slices of Upper Devonian strata. Recent mapping has shown that the movements which drove these slices into their present positions did *not* come from the west-north-west as believed, but came from the south-south-east towards the north-north-west. The piled-up strata were then broken by roughly parallel normal faults, with downthrows towards the west and north-west, and were also warped by the gentle fold of the 'Davidstow Anticline'. The normal faulting is a factor which has had considerable influence on the forms of the cliffs in the Tintagel-Trebarwith Strand area.

The strata along the coast from Boscastle in the north, at Tintagel, and thence southwards to Treligga Common, south of Trebarwith Strand, are of Lower Carboniferous and Upper Devonian age. The latter beds are altered by regional metamorphism to low-grade phyllites in which chloritoid and ottrelite locally occur. The Carboniferous rocks are Lower Culm and show little sign of metamorphism, although they are much contorted. They have been described by Owen (1934, 1950). The general succession, youngest beds at the top, is as follows (Dewey, H., 1909):

	<i>Carboniferous</i>
Lower Culm	Black and grey carbonaceous shales with grit bands. A greenish volcanic band locally occurs at the base.

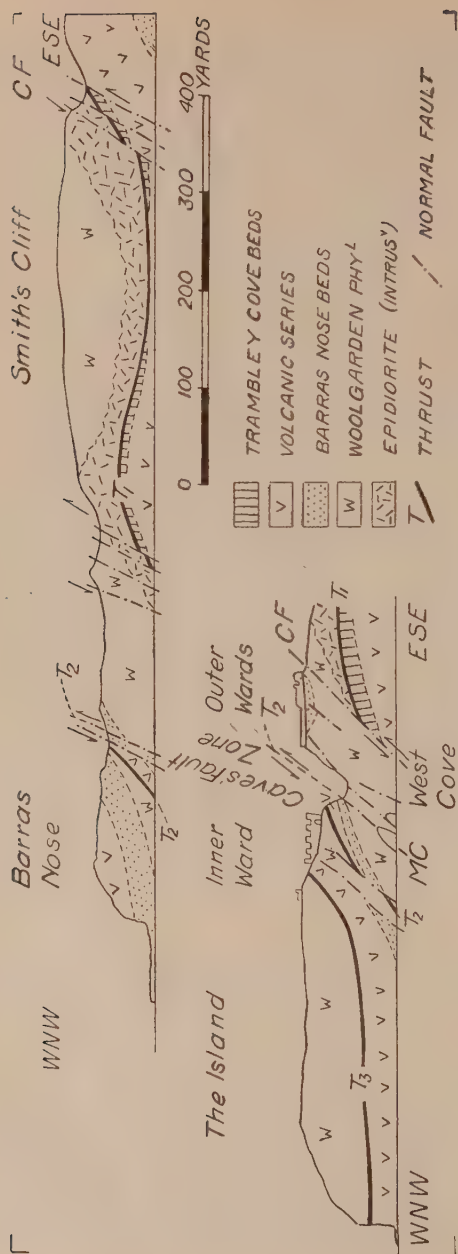


FIG. 1.—Generalised geological cross-sections at Tintagel.
 CF=Castle Fault, MC=Merlin's Cave.

of translation was towards the north-north-west, and is shown by the orientation of various minor structures. These include:

- (1) *Elongation*: Slickenside striations, stretching of lava-pillows, ejecta, amygdulæ, etc.
- (2) *Tension structures*: Tension fractures and boudinage oriented normal to the direction of elongation.
- (3) *Drag-folding and Cleavage*: Fold-axes are normal to the direction of movement, axial planes and cleavage dip to the south-south-east.

The main movements were of course along the thrust-planes, but there was also slip throughout the pile of phyllites analogous to irregular sliding of a pack of cards, and 'the motion took place most readily along the direction of bedding' (Parkinson, J., 1903, p. 410). Consequently the minor structures or tectonic weathercocks of the types mentioned, are not confined to the shear zones, but may occur in any exposure over the whole area.

Around Boscastle, in the Culm beds, zig-zag folding is predominant. The general dip is to the north, but the folds indicate a down-dip movement, that is, the upper beds moved north-north-westerly relative to those below (Plate 4A; see also Owen, D. E., 1934, pl. 41b; Fourmarier, P., 1936, p. 1032).

In the Devonian beds drag-folds are less common than were the zig-zags in the Culm, but their axial trends and the direction of overturning are similar. Stretching structures, such as boudinage, are also parallel to these axes of folding. Elongation structures are best seen in the volcanic rocks on Trebarwith Strand where lava-pillows and ejecta are drawn out in the direction of movement and trend north-north-west at right angles to the drag-fold axes (Wilson, G., 1951, fig. 10).

The movements on the normal faults, which throw down to the west and north-west, were deduced by similar structures. These include drag of the beds on either side of the fault-planes, the formation and orientations of tension-fractures, and in some cases drag-folding, all of which indicated a down-dip movement (Wilson, G., 1951, pl. 30, fig. 13). The important fault-zones have been given local names: the *Castle Fault* runs from West Cove, up past the Castle Gateway, across the valley of the stream from Trevena, and thence to the east end of Smith's Cliff. The *Caves Fault Zone* forms the spectacular zone of faulting which runs up the cliffs of The Island, thence it crosses Tintagel Haven and passes northwards out to sea at Barras Gog (West). Other normal faults lie between these two main zones. The sea-cliffs both to the north and south of Tintagel are in places cut by similar faults which are all members of the same group.

The importance of these two movements—the thrusting and the normal faulting—from a morphological point of view, is their production of planes of weakness in the rocks. The thrusts are more or less flat and are not always well marked, but the normal faults have formed sloping shear-zones along which wave-action at any level can

do much damage. Additional planes of weakness in the form of joint systems have resulted from both tectonic movements, and these too have been utilised by the wave-attack on the cliffs.

Although joints may form in rocks on almost any bearing, there are certain preferred directions, relative to the direction of the movement which has taken place, that can be recognised as being optimum joint-orientations (Cloos, E., 1937; Willis, B. and R., 1934). These are shown in Fig. 2 in which the three structural axes, a , b , and c are also indicated (Wilson, G., 1946, footnote on p. 265; Cloos, E., 1937): a is the direction in which the movement took place; it is that of translation; b is normal to a , and is the direction about which

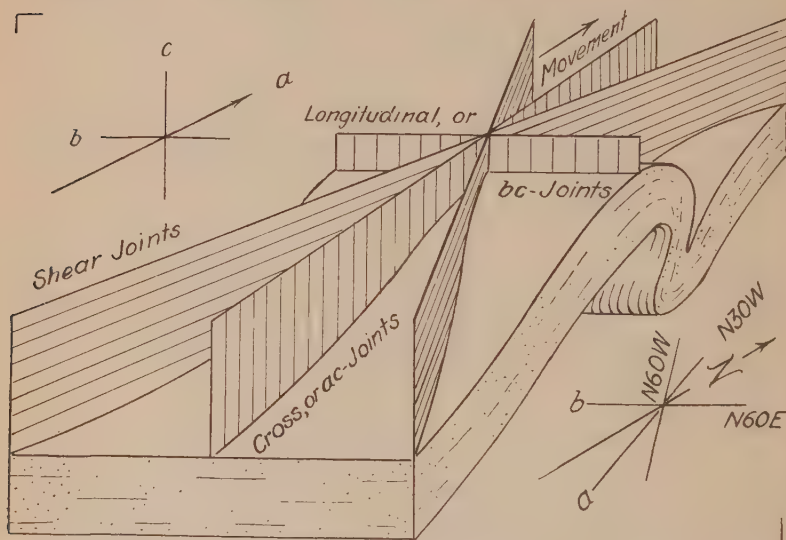


FIG. 2.—The main directions of jointing in relation to the folding. The three structural axes, a , b , and c are indicated, and the orientation of the diagram, in respect to the Tintagel area, is shown in the lower right-hand corner.

rotation-structures due to the movement would develop. It is recognised in the field by the trends of fold axes and commonly by minor corrugations. Here it is also shown in addition by the strikes of tension fractures and the elongation directions of boudins; c is normal to a and b , and in this area it is approximately vertical.

The relationship of the important joint-directions to the movement is illustrated in Fig. 2, and it will be seen that the joints occur in two main systems. The first, comprising dip- and strike-joints, are those in the ac -plane (*cross-joints*) and those which are parallel to b (*longitudinal joints*) respectively. The former are common in most folded regions. Strike- or longitudinal joints are often inclined, and their

orientation may be influenced by cleavage-directions, etc. Some are filled with quartz or calcite, and others gape open as a result of tensional drag due to continued local movement of the rocks. Quartz-filled fractures are well seen in the cliffs between Merlin's Cave and Tintagel Head and in the epidiorite at the foot of the waterfall in

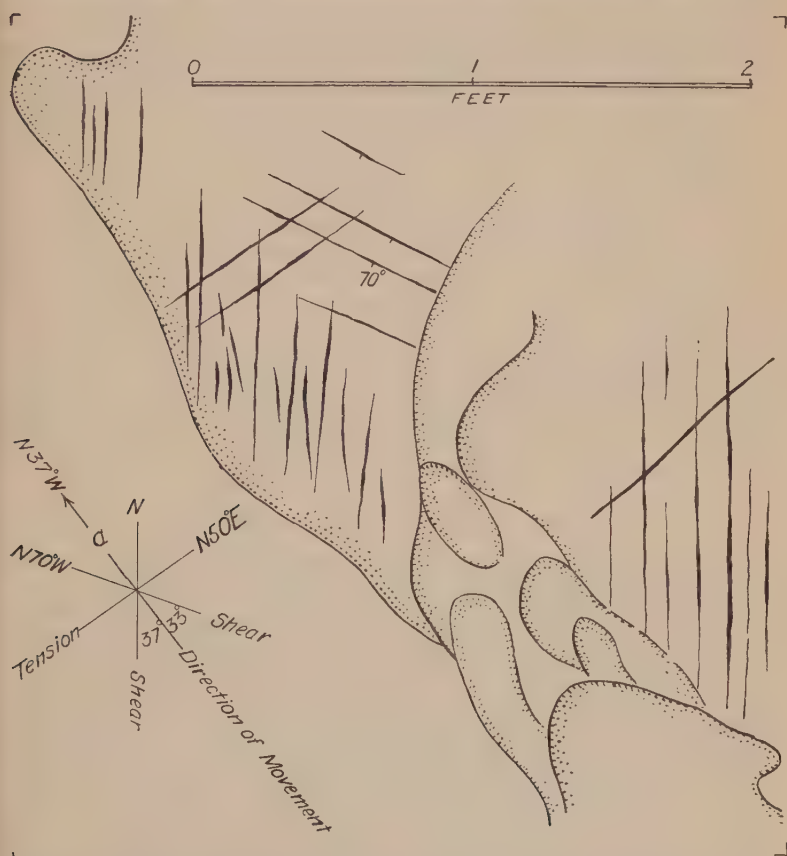


FIG. 3.—Sketch of a horizontal rock-surface, showing joint-patterns in deformed pillow-lava and their relation to the movement directions. Trebarwith Strand.

Tintagel Haven. The two other joint sets form *oblique joints*, complementary to each other, and are more or less symmetrically arranged on either side of the direction of movement *a*. They commonly make an angle of less than 45° with the *a*-axis. These are shear-joints, and their relationship to the rock-deformation and the other structures is seen in small scale among the elongated pillows of Trebarwith Strand (Fig. 3).

It is unusual for all these joint-directions to be equally well developed over the whole area; the formation of one or more sets of joints may prevent the development of others by relieving the stresses responsible.

The joints of the Tintagel area, which are related to the overthrust movements, result from a drive towards N.30°–35°W. Vertical cross-joints striking in that general direction are well developed; *bc*-joints at right-angles to this direction are locally important. Oblique joints are nearly as common as cross-joints; one set only, however, has developed almost to the exclusion of the other. North-south joints, which strike 30° to 35° east of the direction of movement, are met with throughout the area. The joints, which represent the complementary shear-direction, about N.60°–70°W., are relatively rare.

Joints, which are connected with the normal faulting movements and show no relation to the earlier thrust-structures, are locally of importance. They lie roughly parallel to the dislocations, strike north-east south-west and dip about 45° to the north-west.

The influence of these many structural planes of weakness cannot be neglected when the local evolution of the coastline is considered. All of them, dip and strike of bedding, thrusting, faulting and jointing, as well as rock-type, have played their part to a greater or lesser degree in guiding the agents of erosion, and share the responsibility for the development of spectacular cliffs of this coast.

3. STRUCTURE AND CLIFF-FORM

It is generally agreed that erosion by unarmed waves on a stretch of cliff-coast in tough homogeneous rock is slow, and such cliffs may be fairly old. Where the rock is not homogeneous, however, wave action will, as soon as planes or zones of weakness are exposed, break up a smooth and orderly rocky coast and will develop local crenulations. Thus resistant ramparts become indented by narrow joint-controlled inlets, locally termed 'guts' or 'gugs'; fault-zones are eroded into chasms or caves; and landslips develop on undercut seaward dipping bedding-planes and inclined fractures. By means of narrow channels, wave-action can penetrate into more easily eroded zones lying behind the resistant rocks which formed the original cliff-line. Once soft beds or a fault-zone of crushed rock are reached in this way, the attack proceeds laterally along them; if these are sloping the rocks are undercut and falls or slides are promoted. Narrow inlets more or less parallel to the coast are thus formed.¹ The joining together of such inlets leads to the development of stacks, which, once isolated, are 'mopped up' in due course.

Downward corrosion by streams also tends to breach the regular cliff-line. The sides of estuaries form funnel-shaped openings into

¹ The writer has observed inlets formed in this way among the 'geos' of Farr Point, Bettyhill, Sutherland. Other better known examples occur at Lulworth Cove, Dorset.

which pile seas that arm themselves with alluvial detritus. Scour and erosion of that side of the estuary which faces towards the more powerful storm-winds, are thus promoted, and again zones of weakness behind the main cliffs may come under the influence of marine attack.

All these factors have played parts of varying importance in guiding the wave-attack on this coast. In some cases two or three factors have combined, and the picturesque scenery of the cliffs is largely dependent on the variety of structural guides available. This can best be illustrated by considering various stretches of the coast and their relationships to the local geological structures.

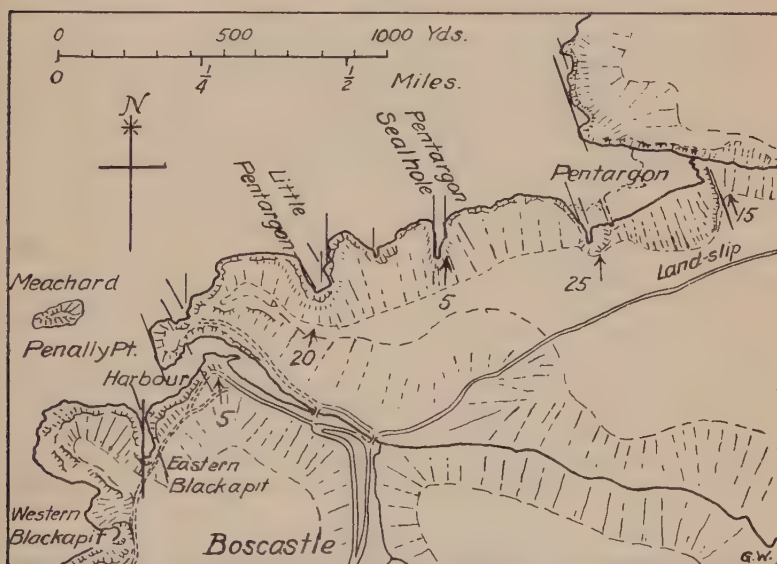


FIG. 4.—Map of the coast around Boscastle and Pentargon, showing the Pentargon hog's-back cliff and the strike-directions of local steeply dipping joints.

The coast immediately north of Boscastle, between Penally Point and the inlet of Pentargon, is formed of beds which dip northerly (Fig. 4). The cliffs here are recognised as having typical hog's-back form, and their upper, even, slope terminates in the flat cultivated surface of the Trevena Platform. Downwards, the grassy incline ends abruptly in vertical and locally under-cut sea-cliffs. The slope closely corresponds to the general angle of dip of the beds on the south side of the inlet; but the north shore is a steep scarp-type of cliff. Within Pentargon itself is one of the few local wave-cut platforms which correspond with the present sea-level, and above this area, where ac-

tive erosion is taking place, the ground to the south is slipping seawards. The more central part of this northward facing coast has an appearance of stability. The hog's-back slope seems to be a continuation of the valley of the stream which flows into the sea at the head of Pentargon. This part has not been cut back to the same extent as the present landslipping portion, because the relatively deep-water below the cliffs did not permit the waves to arm themselves with rock-débris, thus slowing down erosion.

The importance of jointing in the development of steep-sided narrow guts is well exemplified at Pentargon (Balchin, W. G. V., 1946). In addition, the cliff at the head of the inlet itself is largely a joint-plane striking $N.25^{\circ}W.$ —a cross- or *ac*-joint—and the points of the headlands north of the bay are truncated by similar planes. Pentargon Sealhole, the cliffs of which overhang a wave-cut nip, is eroded along north-south joints. The shape of Little Pentargon is controlled by intersecting north-south and $N.20^{\circ}W.$ joints.

The estuary of the Valency at Boscastle is a drowned valley, but evidence that the sea-level may have been higher than at present, is suggested by a prominent little wave-cut nip in the cliffs above the present highwater mark (Plate 2A). The rocks on either side of the river mouth are strongly jointed, and the end of Penally Point is cut off by fractures striking $N.20^{\circ}W.$ Similar joints guided the erosion of Eastern Blackapit.

The Boscastle Blow-Hole (Plate 2A) which passes through the neck of land joining Penally Point to the mainland is also eroded along such joint-planes. At low and mid-tides the south exit of the tunnel can be seen, and when a big sea is running outside great jets of water are thrown into Boscastle Harbour. The mouth of the hole is covered at high tide. Anyone who has seen this blow-hole belching forth its great gushes of water and spray, cannot but appreciate the power of waves to erode by compression of air or water in joints and rock-crevices.

South of Boscastle, erosion along joint-planes leads to many irregularities in the coast. Grower Gut is an example of a rectangular inlet which has been cut back along west-north-westerly or oblique joints. The fault, which can be seen at its head, continues northwards and a narrow cave has been eroded along it near California Quarry.

The sloping hog's-back cliff-faces between Grower Gut and Boscastle Old Quarry (Fig. 5) are controlled by joints, and in places by minor normal faults, which dip about 45° to the north-west. A second set of joints striking $N.30^{\circ}$ to $40^{\circ}W.$ intersects the former, and erosion along the two sets has led to the local development of a rectangular shore-pattern. The stretch of cliff, which runs north-west from Boscastle Old Quarry to Short Island, is another hog's-back, here controlled by the dip of the bedding. Wave-attack along steeply dipping joints has resulted in the formation of small stacks and tidal reefs, as well as vertical gullies which cut the cliffs.

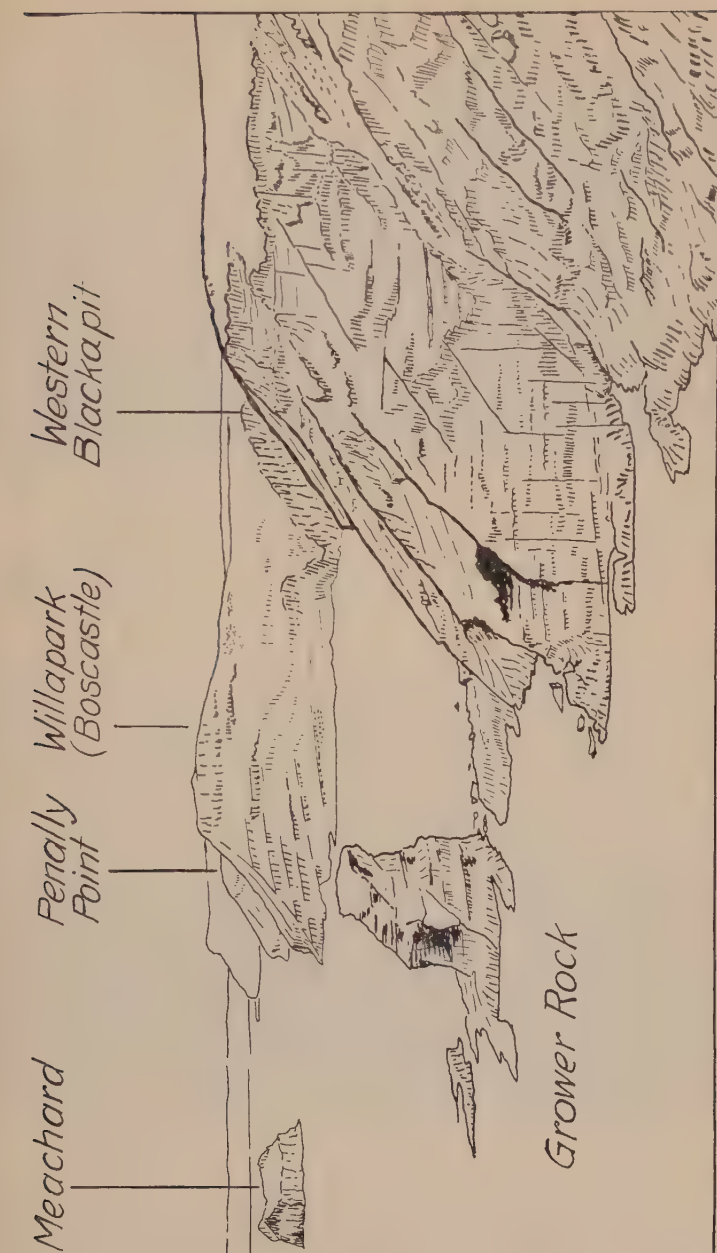


FIG. 5.—Hog's-back cliffs between Boscastle Old Quarry and Boscastle, looking north-easterly. (From a photograph.)

Short and Long Islands are great stacks rising to the level of the Trevena Platform (Dewey, H., 1914, pl. 2A), and are separated from the mainland by erosion along joints. In this they differ from Saddle Rocks which, together with Trambley Cove, owe their existence to normal faults. Erosion here has attacked along a fault-zone which forms the south side of Saddle Rocks and the north side of the Trambley Cove re-entrant. The bedding dips northward towards the nearly vertical dislocation. Trambley Cove thus has a wedge-like form: the north side has broken away along the fault-planes, and the south side has slipped down the dip-slope of the Trambley Cove Beds.

Trewethet Gut, the mouth of Rocky Valley, and a precipitous inlet, 200 yds. south of the latter, are all largely controlled by vertical north-north-westerly cross-joints. North and south of Rocky Valley, however, inclined joints associated with minor normal faults and dipping about 45° north-westerly, exercise considerable influence on the forms of the cliffs. Where the attack has laid bare these planes, a sloping glacia up which the swash of the waves largely expends itself, has been developed. The effect of undercutting along such inclined surfaces leads to the occurrence of overhanging cliffs and to rock-falls, with the eventual production of an evenly sloping cliff.

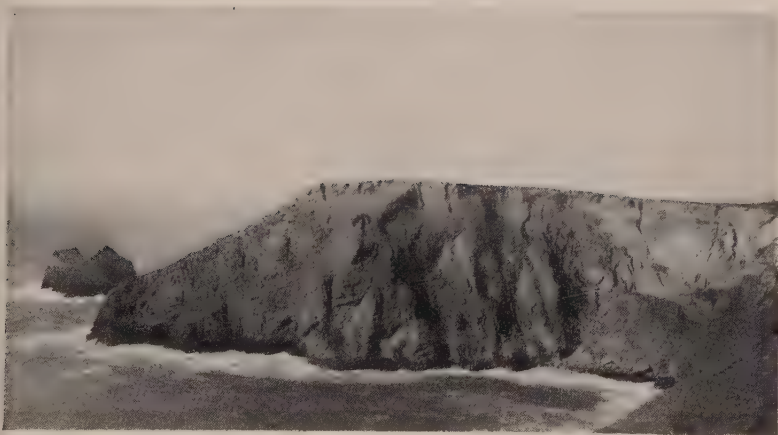
The walls of Bossiney Haven are largely vertical joint-planes, and enlargement of such fractures has produced the rock-pillars which form the well-known Elephant Rock. There is a marked swing in the strike of the beds about here, and the bay of Bossiney Haven is eroded in the nose of the gently plunging Davidstow Anticline.

Between Bossiney Haven and Lye Cove is a rounded headland composed of altered volcanic rocks, now chloritic schists. This is one of the few local examples of such rocks forming a promontory. It is, however, noteworthy that on the opposite side of the bay, the volcanic rocks do not produce any corresponding feature.

The promontory of Willapark, Lye Rock and The Sisters are composed of Tredorn Phyllites which are much jointed. The great chasm between Willapark and Lye Rock is eroded along $N.30^\circ W.$ or *ac*-joint-planes; and the vertical flat-topped cliffs on the south-west side of the big promontory have developed on shear joint-planes striking $N.60^\circ$ to $65^\circ W.$, and *ac*-joints at $N.30^\circ W.$ Inclined jointing, which dips north-westerly, also plays a part in the form of Willapark. Such joint-planes can be seen cutting across the face of Lye Rock, and the sloping north-west faces of both Lye Rock and of Willapark are largely controlled by these fractures. This seaward face of the promontory presents an excellent example of a hog's-back (Plate 2B). The vertical cliff at the foot of the slope is about 50ft. high, and the remaining 250ft. to the top is taken up by one even, structurally controlled, sloping surface. The gap between Willapark and The Sisters, as well as that between the two stacks, are eroded along joints. Balchin (1946) points out how commonly erosion along joints has led to the formation of stacks in this particular type of rock—the



A.—PENALLY POINT AND THE BOSCASTLE BLOW-HOLE.



B.—WILLAPARK AND THE SISTERS FROM SMITH'S CLIFF



Tredorn Phyllite—and certainly one sees from the map the reason for this statement.

The hog's-back cliff-line which can be followed from Lye Cove, across the isthmus of Willapark to Gullastem, and thence to the re-entrant at the east end of Smith's Cliff, is formed by a combination of dip-slope and normal faulting. The soft Trambly Cove Beds, which are lying on the top of the Volcanic Series, are broken by normal step-faults. The bedding and the faults both dip seawards, i.e., towards the north-west (Fig. 6). The dual effects of the dip of the bedding and of the fault-planes have been to provide sloping slip-surfaces from

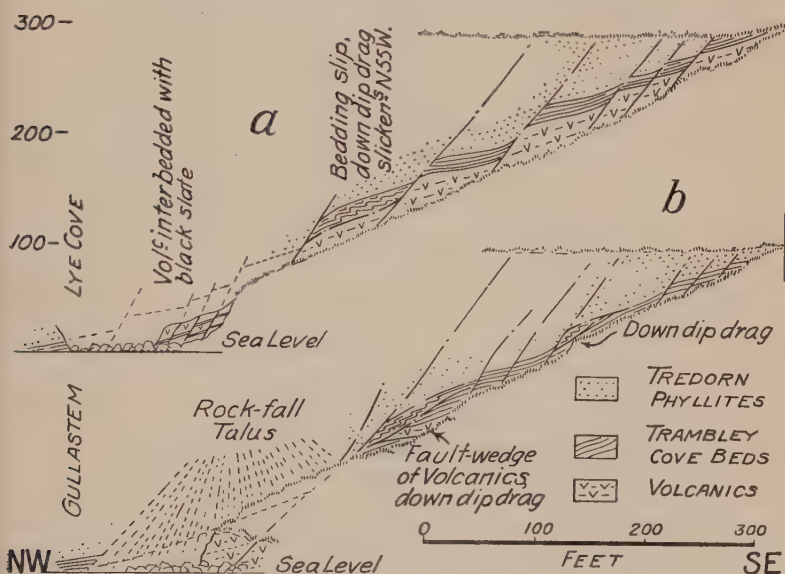


FIG. 6.—Sections showing the relationship between the hog's-back cliff on either side of the Willapark isthmus and the geological structure. (a) Section to the north-east; (b) Section to the south-west of the isthmus.

which the overlying and softer rocks were peeled off. The top of the Volcanic Series forms the present slope, and, combined with the marine attack at the foot, it has produced the present slope-over-wall cliff. Wave-erosion along steeply dipping joints is locally breaching the face of volcanic rocks and forms rectangular re-entrants in the cliff. Continuation of attack along these planes will eventually penetrate into the less resistant Barras Nose Beds below the Volcanic Series; the direction of excavation should then turn along the strike of the strata.

Between Smith's Cliff and Barras Nose the geological structure becomes more complex than hitherto. The Castle Fault is responsible

for the appearance of the Flat Thrust (T_1) near the foot of the cliff. The thrust-zone is locally eroded into a horizontal saw-cut above which the cliffs overhang. The sole of the thrust is a flat ledge of altered volcanic rock partly covered by rock-fall and slide-débris. West of Smith's Cliff it is found that cross-joints striking $N.35^\circ W.$ become common, and inlets with vertical or undercut walls having this orientation have been eroded. The cliff between East and West Barras Gugs is seamed with enlarged vertical *ac*-joints, but the two 'gugs' themselves are the result of erosion on normal faults (Fig. 7).

The faults of East and West Barras Gugs strike roughly at right-angles to the coast, and the two inlets, though steep-sided, are asymmetrical. They can both be descended (with difficulty) on their sloping eastern surfaces formed by the stripped fault-planes and down-dragged beds. Their western walls are vertical or overhanging.

The fault in West Barras Gue continues through the isthmus and is eroded into a precipitous chasm ending in a cave. From here this line of dislocation—the Caves Fault Zone—splits, and is responsible for the group of faults along which caves have been eroded on both sides of Tintagel Haven (Plate 3A). Two of these caves are 'through caves'. One is a low tunnel passing beneath the rectangular promontory of Blackarock; the other is Merlin's Cave which passes below the ruins of the Castle on The Island from the Haven to the corner of West Cove. In rough weather with a south-westerly gale the seas, piling through Merlin's Cave into the Haven, form a very impressive spectacle.

The Caves Fault Zone played an important rôle in the later development of Tintagel Haven. This inlet separating The Island from Barras Nose, is the estuary of the Trevena stream which now cataracts down some 40ft. to 45ft. on to the bay-head beach. The former continuation of this stream and its valley can still to a certain extent be extrapolated (Fig. 7). The levels of the top of the Blackarock promontory and of the projecting step upon which stands the Iron Gate, would roughly coincide with the existing valley floor if it were prolonged seawards at its present gradient, and the grass- and rock-slope, rising above the Iron Gate on The Island, is accordant with the south-west side of the present Trevena valley. A one-time tributary of this prolonged river is seen in the smaller brook which now cascades into the sea between Barras Nose and Blackarock. It is evident that this line of drainage has had considerable influence on guiding the marine attack inland, and was responsible for the initiation of the excavation of the Haven.

The base of the seaward cliffs of The Island is composed of sheared volcanic rocks. Similar rocks occur as an outlier on Barras Nose and dip gently to the north-west. It seems probable, therefore, that the original coast-line, from which this portion of the present shore has been carved, lay west and north-west of these two promontories, and consisted largely of the relatively tough Volcanic Series.

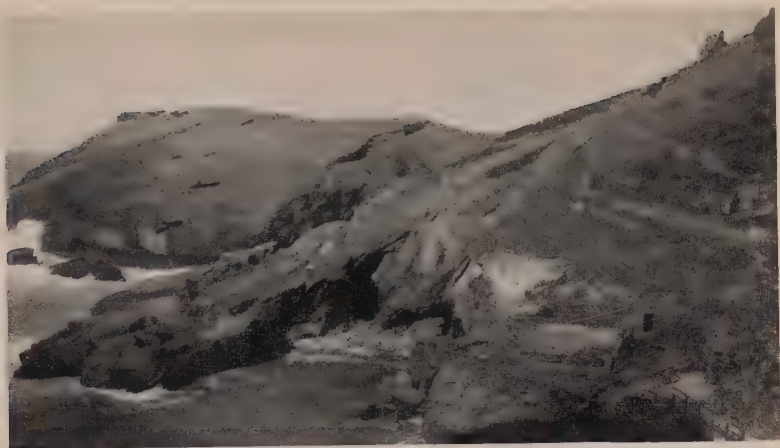


FIG. 7.—The evolution of Tintagel Haven. The first stage is shown by a heavy line; the directions of the second stage of the wave-attack is indicated by a branching arrow. Merlin's Cave is shown passing below the Inner Ward. Thin lines represent prominent joint-directions. CFZ=Caves Fault Zone, CF=Castle Fault.

The mouth of the prolonged Trevena stream would make a re-entrant in this shore-line, and would also be responsible for the thinning or possibly the cutting through to sea level of the volcanic facing. The stream-mouth would thus assist in exposing to wave-attack that portion of the coast where the hard rock-band was thinnest or even broken. North-north-westerly (cross) and north-south (oblique) jointing would guide the first stages of the attack inland, and blocks would tend to break away along these and east-north-east (or *bc*) joints. Once the outer north-westerly dipping volcanic band had been penetrated, it must have been undermined by the erosion of the softer Barras Nose Beds below it. This would be particularly so on the Barras Nose side of the Haven where the dip is steeper and the rocks are more exposed to the full force of westerly gales. Here is another place where a wave-cut platform corresponding to the present sea-level occurs.

The shape of the outer part of the Haven agrees with the general joint-pattern, by which its excavation was undoubtedly controlled (Fig. 7). The pattern is simple on the south-west side of the Haven, but is more elaborate on the east or Barras Nose side. This joint-control seems to have continued as far as the line between the Iron Gate and the south-west corner of Barras Nose. Here the presence of the tougher Woolgarden Phyllites made itself felt, and the Haven narrows markedly; but the trend of the Barras Nose cliff still reflects the importance of north-north-west jointing. South-east of and below the Woolgarden Phyllites is the thrust (T_2), a tight dislocation which does not act as a significant zone of weakness. It separates the Phyllites from an underlying band of volcanic rocks. This band of tough, but well-jointed, chlorite-schist formed a natural barrier protecting the head of the bay, even as similar rocks now do along the coast between Willapark and Smith's Cliff.

Eventually this protective wall was broken through, but its abutments can be recognised in Barras Nose, Blackarock and The Island. One can picture the manner in which it was pierced. The waves would be attacking a sloping rock-face traversed by joints, from which blocks would periodically be displaced. During a heavy sea the water would be spouting from these fractures, even as it does on Blackarock today. Massive joint-bounded blocks would thus be wrenched away from their setting and would tend to slip seawards down the dip-slope, in a manner similar to that seen at present at Trebarwith Strand. Once a breach had been opened through the resistant rock barrier the waves would encounter the underlying soft and shattered rocks of the Barras Nose Beds and the Caves Fault Zone. The attack would then fan outwards on one or both sides of the breach, as shown by branching arrows in Fig. 7. The immediate result of this break-through was the removal of support from behind the seaward-dipping volcanic rocks which would thereupon collapse and be broken up piece by piece. At the same time the waves, armed



A.—BLACKROCK PROMONTORY AND THE CAVES FAULT ZONE
AT TINTAGEL HAVEN.



B.—THE CASTLE FAULT AT WEST COVE.

[To face p. 36.

with rock-fragments, would undermine the lower part of the foot-wall slope of the Caves Fault Zone, thus causing further slip of the hanging-wall rocks down the fault-planes which here dip at about 35° to 45° . Such slip has been responsible for the formation of the long-sloping fault-controlled hog's-back which rises from the present cliffs up to the 300-ft. platform near the Hotel (Plate 3A). It seems probable that the caves were driven into the fault-zone within a short time of the gap being formed. The waves surging through the breach into a restricted space would, in the early stages, have greater tunnelling power than later when the bay was more fully developed.

Apart from the main break leading into the head of Tintagel Haven, a second gap was also formed between Blackarock and Barras Nose, on the line of the little tributary stream. The isthmus connecting Barras Nose with the mainland is now being tunnelled along the fault-zone in a manner similar to that outlined above. In Barras Gulg (West) on the north side of the isthmus the faults converge into one main dislocation which is a gouge-filled fissure, quite incapable of resisting erosion if it were more exposed to the prevailing wind direction.

The west face of the buttress, upon which stand the Outer Wards of the Castle, has been largely formed by the slipping away of rock from steeply dipping fault-surfaces. Hanging-wall remnants locally adhere to the fault-planes, and rock-falls occur from time to time. The erosion of the ridge of land connecting The Island with the mainland has been accelerated by the numerous fault-planes which cross the gap. According to Radford (1936, pp. 3-4) when the Castle was first built, in about 1145, parts of it 'stood on the isthmus which at that time connected the headland with the mainland'. In 1235-40 the wards on the mainland were built; 'At this period a bridge connected the two parts of the Castle. . . . By the 16th century the gap between the island and the mainland had widened to almost its present proportions.' Rock-falls from the gap have happened recently, and on the south side the slope as a whole is very insecure. The writer has been asked by workmen on the Castle whether a through-cave ever existed below the gap. It seems quite possible, but fallen rock and rubble mask the evidence for or against.

Merlin's Cave, however, passes from Tintagel Haven, below the Castle on The Island, to the West Cove. It has been eroded along a normal fault which is a member of the Caves Fault Zone. In this case it is doubtful whether the waves in Tintagel Haven were actually responsible for driving the whole tunnel. The present-day erosion in the cave is almost entirely due to seas piling in from the south-west end, and it seems probable that such waves were dominantly responsible for the cave. Even so, waves in the Haven may quite well have started eroding along the north-east end of the fault-plane, and they probably played a considerable part in enlarging the cave entrance. It is of interest to note that above Merlin's Cave, at its south-

west end, there is another smaller cave containing striking slickensided grooving and accessible from a ledge. One is tempted to speculate on the age of the sea-level which was responsible for the formation of this little feature.

West Cove owes its origin almost entirely to excavation along the strike of several fault-planes. Of these, the Castle Fault is the most important (Plate 3B). This dislocation, rising from beneath the beach-deposits, runs up the re-entrant in the east corner of the Cove to the Castle Gateway. The effect of undercutting by the sea at the base of the plane of weakness due to the fault, and also to fractures formed by *ac*-joints striking N.25°–30°W., have resulted in the removal of a great downward-tapering wedge of rock from below the Outer Wards of the Castle. Somewhat similar re-entrants on a smaller scale have been known to form on the sides of artificial excavations which cut obliquely across fault-zones (McCallum, R. T., 1930; Blyth, F. G. H., 1943, p. 251). The vertical wall, upon which stand the Outer Wards, abuts against a sloping, grass-covered surface: the foot-wall of the Castle Fault. At the foot of this grassy slope is a sea-cliff which, at the back of the Cove, is merely a step, but towards the sea rapidly rises into a formidable precipice. This side of the West Cove is, therefore, a youthful hog's-back which cuts across the older slope-over-wall feature that forms the main cliff-line extending to the south.

The fact that the wall of the Castle gateway defences—which for obvious reasons must have been built along the extreme edge of the vertical precipice—is still standing, was considered by Guilcher (1949, p. 714 and fig. 10E) as evidence that the cliffs were becoming stabilised. The Castle wall, however, is only unbroken where the base of the vertical cliff is resting on the inclined fault-plane. Where the precipice descends sheer to the West Cove beach and its base is more exposed to marine attack, the original Castle wall above has disappeared. The low wall which now separates the visitor from *un gouffre vertigineux* has only recently been constructed along an edge which had broken away. West Cove beach is covered with very large boulders, and high tide now barely reaches the foot of the precipice. The débris of ancient rock-falls is still to a great extent protecting the base of the cliff from erosion. Waves will arm themselves with small boulders or rock fragments, but their erosive force is checked by big ones. 'The secret of power . . . is not the big stick. It's the liftable stick.'—*Kipling*.

The tunnelling of Merlin's Cave and the similar formation of a big, more or less parallel, but inaccessible cavern between it and Tintagel Head (see Dewey, H., 1909, fig. 5; 1914, pl. 4), suggest the tactics of the wave-attack which evolved the West Cove. The waves driving up from the south-west worked their way along the various shatter-zones, with the Castle Fault as their south-eastern boundary. There are here several fault-zones and the tunnels would

not be widely spaced, but would rather tend to connect and collapse into each other. Erosion would also be active along the north-north-westerly *ac*-joints which are strongly developed hereabouts, with the consequent breaking away of the cave-portals to form a retreating cliff similar to that now seen below the Outer Wards of the Castle. This modern cliff is itself controlled by these cross-joints. The narrow Cove marks the width of the frontal wave-attack; behind, that is to the south, the cliffs depart from the plane of the Castle Fault: they swing southerly towards Lambshouse Quarry. Along this stretch they are unbroken by faults, and their slope-over-wall profile is irregular. The original sloping cliff formed by the stripping of the fault-plane, has retreated parallel to itself probably under subaerial periglacial erosion, and the present-day cliff is the result of 'freshening' by wave-attack, as Cotton (1951) suggests, during post-glacial or inter-glacial stages.

There is little doubt that The Island, a salient of the coast-line, owes its existence to the fact that the base of its cliffs to the south, west, and north is composed of resistant flat-lying volcanic rocks. On these rest the phyllites which, as a klippe, form the main mass of the headland. The present-day marine action seems to be having little effect on the tough rocks forming the seaward face of The Island. On the landward side, however, where the cliffs are cut by fault-zones, the sedimentary beds below the Volcanic Series are brought up into the range of wave-erosion, and caves are being driven into and through the promontory. In time, the south-east side, with its Castle ruins, will eventually collapse, and The Island will fully justify its title.

Southwards from The Island, and for a distance of about three miles, the points of headlands all lie on an approximately straight line. This line is indented by West Cove in the north, the beach of Trebarwith Strand, and by Backway's Cove in the south, beyond which it can be seen to run close, and parallel, to the cliffs as far as Tregonnic Tail, about one mile south of Dennis Point. This line of headlands, seen in plan, is analogous to the accordance of mountain summits which one sees in profile. It marks the general position of an older shore-line now locally embayed by more youthful retrogression.

The open bay of Trebarwith Strand lies between the headlands of Penhallic Point on the north and Dennis Point on the south (Fig. 8). The cliffs are stepped back about 600 yards at Hole Beach and 200 yards at Port William from the line tangential to the two points. The stretch between Penhallic Point and Hole Beach is composed of closely-jointed Delabole Slate overlain by Woolgarden Phyllites. It is strongly indented, and the cliff-foot is largely hidden by rock-fall talus. At Hole Beach are two converging normal faults which strike south-south-westerly. Their seaward prolongation passes between Dennis Point and Gull Island, and would cross the line joining the

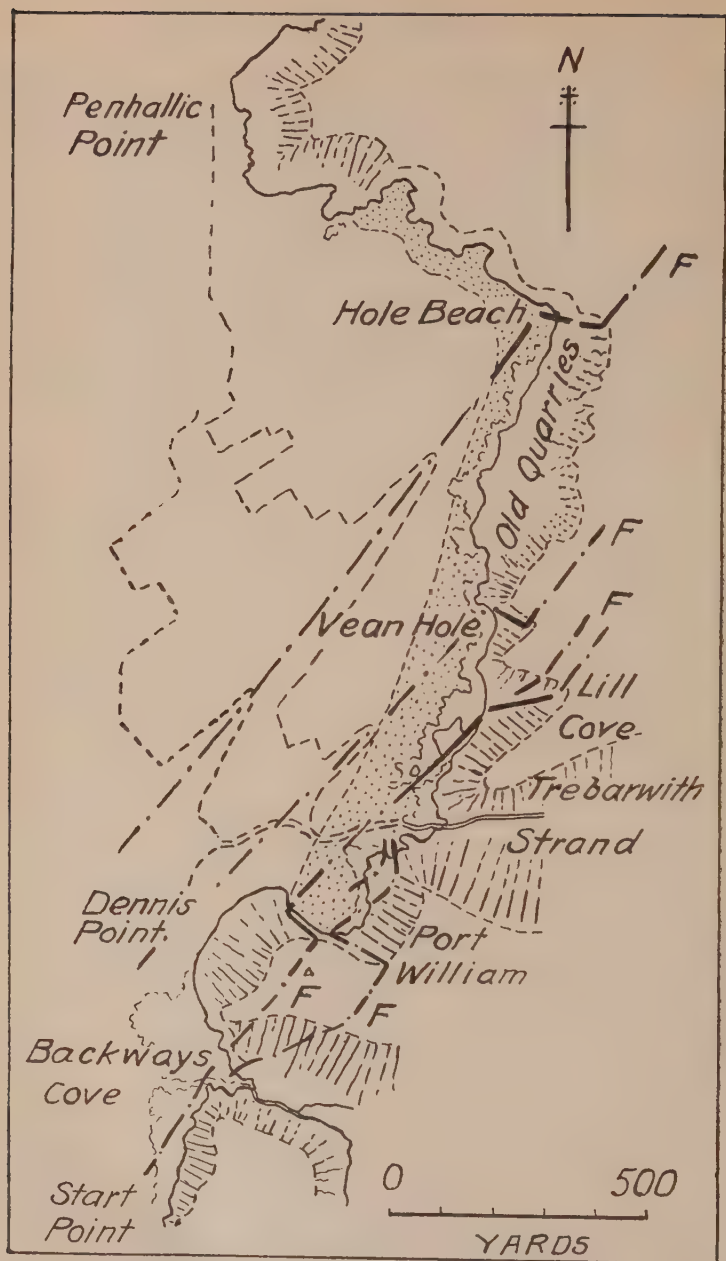


FIG. 8.—The evolution of the Trebarwith Strand embayment by erosion guided by zones of normal faulting (F).

headlands opposite the mouth of the Trebarwith Strand valley. In the cliffs south of Hole Beach these faults are responsible for the re-appearance of the Volcanic Series overlain by sheared phyllites above which appears the Flat Thrust (T_1). Above the thrust are Delabole Slates, now extensively quarried, and Woolgarden Phyllites. The volcanic rocks form a sloping wave-eroded apron at the foot of the cliffs, and they, together with the sedimentary rocks above them, dip gently westwards. All these strata are broken by other normal faults at Veian Hole, Lill Cove and in Port William. At this last locality, Tredorn Phyllites are thrown down below sea-level and form Dennis Point; the faults responsible can be seen running diagonally up the great 300-ft. cliff which flanks the point. An extensive sandy beach now covers the foreshore of the embayment, but at high tide the waves break locally against the phyllites of the vertical cliff above its plinth of volcanic rocks.

The mouth of the prolonged Trebarwith Strand stream must once have formed some kind of re-entrant in the initial coastline; and, as stated above, this inlet approximately coincided with the point where the Hole Beach faults crossed this coast. On the seaward side of the fault-zone the rocks would consist of slates and phyllites; on the landward side there would be similar rock-types resting on the sheared phyllites of the Flat Thrust (T_1). Powerful storm-waves driven from the south-west—the direction of maximum fetch—would attack directly along the line of the faults and shattered rocks. The attack thus proceeded in the same manner as that recognised at West Cove, and there was a general retrogression from the south-south-west towards the present cliff-line between Penhallic Point and Hole Beach. The main line of marine advance was probably along the zone of dislocation, and would form a gully having an asymmetrical cross-section. The west side would be steep and undercut, the east side inclined in conformity with the fault-planes and, to a certain extent, with the local dip. Rock-falls and landslips, from the two sides respectively, must have kept the waves armed with débris, and steady retreat of the cliffs would occur. In this way the other fault-zones were exposed, and the attack also proceeded along them, as can be observed on the Veian Hole and Lill Cove faults at the present time. On each of the fault-groups the cliff-line can be seen to be stepped back, with the formation of a re-entrant of which one side is the fault-plane. At Hole Beach the sloping cliff-face has retreated back from, and below the normal fault-plane. Such retreat of the cliff parallel to itself probably accounts for the slope-over-wall form—now partly destroyed by quarrying—which characterised the original cliff between Hole Beach and Trebarwith Strand (Balchin, W. G. V., 1946, p. 334).

The embayment has thus been eroded by attack along oblique zones of weakness with the concomitant removal of the material lying between parallel faults. As long as the attack was on rocks com-

posed of slates and phyllites and their sheared equivalents, erosion must have been fairly easy. But now, from Hole Beach to Port William, the exposed base of the sea-cliff is composed of the more resistant Volcanic Series, dipping gently to the west and in which jointing is widely spaced. These rocks are to a considerable extent protecting the coast from rapid retrogression. Nevertheless they too are not immune from erosion, and large blocks detached along joint-planes can be seen to have slipped down the seaward-dipping planes of stratification.

Port William presents an excellent example of wave-erosion guided by normal faults which dip about 40° to 50° towards N. 75° W. Each fault has a cave eroded at its foot. The outer, most westerly faults connect with those at Lill Cove, and a gully behind a stack on the shore near the latter marks the trace of the dislocation. The whole hillside forming the back or east face of Port William coincides with the foot-wall surface of the lowest fault. Resting on this exposed fault-plane are blocks of rock, loose rubble and soil which require little encouragement to slip downwards. Wave-attack now cutting into the jointed and down-dragged rocks at the foot of the slope, is actively eroding here at the present time, and the writer has several times found rocks which have freshly fallen between successive visits. The hog's-back cliff which is now forming is in an infantile stage! (See Fig. 1 on p. 53 in Field Meeting Report.)

The strike of the normal fault-system, which has been so important in guiding the wave-attack, gradually swings more southerly as the coast is followed towards the south. This is reflected in the form of the coast-line itself. At Barras Gug fault-line chasms and coves are oriented at right-angles to the coast. At Trebarwith Strand the re-entrants eroded along fault-planes are at acute angles to the general line of cliffs; but south of Backway's Cove the regular coast as a whole corresponds to the general projected trend of the fault-planes. The Treligga Cliffs are the result of marine attack working its way by slow piecemeal erosion, unassisted by any marked zones of weakness, into the foot-wall of a fault-zone which is now largely lost from view. This zone is visible in Backways Cove and, at the south side of the inlet, shows as a single fault-face over 100ft. high that has been stripped by rock-falls during the last few years. The influence of such structural planes can also be seen at the south end of the cliffs, where there is extensive land-slipping at Tregonnig Tail, and the cave of Flat Hole is eroded along a fault.¹ The Treligga Cliffs thus owe their regular plan to the fact that they are fault-line cliffs which have suffered but slight retrogression. Similar conditions probably persist even further south where the cliff-line follows a regular, almost straight, course as far as Port Isaac Bay.

¹ About 1500 and 1200 yds. south of Backways Cove respectively.

4. CONCLUSIONS

The coastal morphology of the Tintagel district of North Cornwall is largely dependent on the geological structure of the rocks. Balchin (1946) considered that the north Cornish cliffs were, from a regional standpoint, old and mature. Locally, however, they present many youthful features, and the marine erosion, begun so long ago, is now believed by the writer to have followed in principle the tactics of the present-day wave-attack on the coast. Bedding-planes, joint-planes, and normal faults all formed zones of weakness in the rocks which were picked out by the waves, and the crenulations of the present coast are seen to be controlled by such features. Normal faults appear to have been the most important, especially where they trend at an acute angle to the present coast, and are more or less parallel in strike to the direction of maximum fetch. Erosion, having once begun to make inroads along parallel fault-zones has been able to cut back

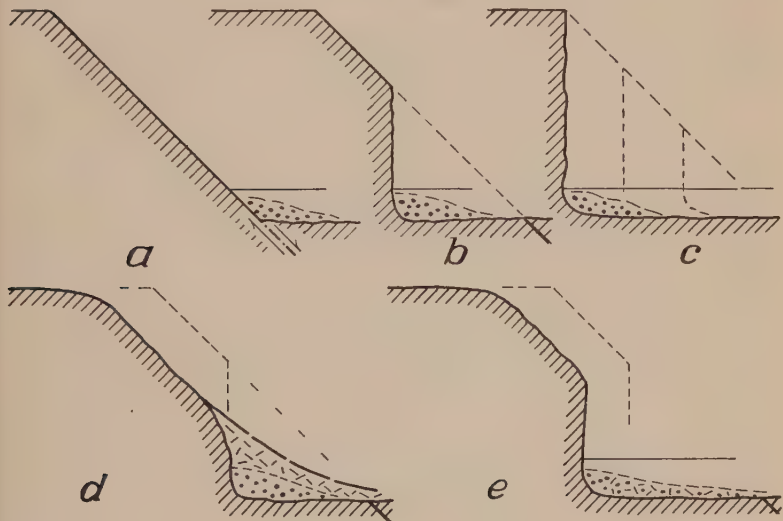


FIG. 9.—The development and retreat of a fault-line cliff.

- a* to *c* by marine erosion; *d* and *e* by two-cycle process, as suggested by Cotton (1951).
- a*.—The stripping of an inclined fault-plane.
- b*.—Wave-erosion develops a slope-over-wall cliff.
- c*.—Continued wave-action destroys the slope, and a flat-topped cliff is formed.
- d*.—Sub-aerial weathering during a period of lowered sea-level results in the retreat of the cliff, and the accumulation of head on top of marine deposits.
- e*.—Return of the sea rejuvenates or 'freshens' the lower face of the cliff.

the cliff-line by the collapse and wearing away of the rock-slices between the inclined shatter-belts.

It was in this way that the cliffs from The Island to Treligga Common were evolved. The strike of the faults diverges slightly from the line of the cliffs, and the dislocations all dip seawards at angles of about 45° . Under such circumstances the cliff-development started with erosion along and the stripping of the fault-plane, and the formation of a sloping surface. Wave-action, attacking at the foot of this slope, undercut it and produced typical slope-over-wall or hog's-back cliffs (Fig. 9 *a* and *b*), which, if the marine activity were powerful, might in turn be destroyed, with the formation of a flat-topped cliff (Fig. 9 *c*; Arber, M. A., 1949, p. 194). Alternatively, as proposed by Cotton (1951), when the sea-level fell during a period of glaciation, the cliff would be subjected to sub-aerial periglacial erosion. This would result in flat-topped cliffs becoming bevelled, and in original hog's-back cliffs being eroded back or retreating parallel to themselves (Bryan, K., 1940; Wood, A., 1942; Penck, A., summarised in Engeln, O. D. von, 1949, pp. 263-4). In this way the initial slope would be retained, and also extended downwards at the expense of the vertical sea-cliff; at the same time the upper edge would tend to become rounded. Eventually the retreating hog's-back would, by erosion above and accumulation below, change to an even continuous slope (Fig. 9 *d*). With the melting of the glacial ice, marine erosion of the cliff-base would begin again as the sea-level rose. Head and talus which had accumulated would be washed away, and the vertical sea-cliff would be disinterred or developed again by 'freshening' (Fig. 9 *e*). Professor Cotton's proposed theory of two-cycle origin for these cliffs explains many of the features observed in this area.

Short stretches of the coast are still recognisable as being true fault-line cliffs. Elsewhere, where the cliffs swing gently back from the line of dislocation, one may find the same slope-over-wall form, but it is of a less clean-cut appearance. These latter cliffs are believed to be eroded fault-line features which have retreated, but have still retained, in a slightly modified form, their original profiles. Such retreat and modification of hog's-back cliffs explains much of the evolution of the present coast-line and accounts for the *raison d'être* of many of the features encountered south of Tintagel.

North and east of The Island the coast changes in character, and in the same area the structures begin to swing around the nose of the Davidstow Anticline. The coast between The Island and Bossiney Haven is crenulated with relatively large havens and headlands, and narrow steeply-sided inlets. The wave-attack is here eroding isthmuses along normal faults and soft beds. It is also penetrating inland along the joint-planes which traverse the rocks in various directions.

The effect of erosion guided by jointing almost to the exclusion of other structures, becomes more and more evident as one proceeds

northwards from Bossiney Haven. Sloping cliffs, which resulted from the stripping of strong inclined joints, stacks isolated by attack along vertical joints and the forms of bays, headlands and blow-holes, all show the effect of the same type of controlling influence.

Over different parts of this coastal stretch the geological structures, which guided the wave-attack, varied in character and orientation, while the attack itself varied in direction and intensity relative to the shore-line. On a coast such as this, where variety in morphology has made the cliff-scenery famous for centuries, no generalisation can be applied to the local evolution of the cliffs. The development of form of each headland, bay, or line of cliff is guided by the geological structures and by their relationship to the direction of effective wave-attack. The rule of *suum cuique* seems to be as applicable here as it is in other branches of geology.

EXPLANATION OF PLATES

1. Geological map of the coastal area around Tintagel, from Boscastle to Treligga Common. [Reproduced from Wilson (1951) by permission of the Council of the Geological Society.]
2. A.—Penally Point and the estuary of the River Valency at Boscastle. The blow-hole at lower right is spouting due to the action of waves on the far side of the isthmus. The raised wave-cut nip is on a level with the horizon.
B.—Willapark and The Sisters from Smith's Cliff, showing the hog's-back profile of the promontory.
3. A.—Blackarock promontory and the Caves Fault Zone at Tintagel Haven. The sloping sky-line on the right is formed by the dip of the fault-planes. Barras Nose in the background.
B.—The Castle Fault at West Cove. The trace of the fault runs up the re-entrant. The vertical cliff is composed of Woolgarden Phyllites capped by (dark) Barras Nose Beds, and forms the hanging-wall of the fault. The grass-slope on the right is the foot-wall of the fault, and corresponds to the fault-plane. The lower part of the slope contains Volcanic Series overlain by Trambley Cove Beds; the upper part is made of Woolgarden Phyllites; between the two is the Flat Thrust (T_1). The cliff is about 250ft. high.

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DISCUSSION

MISS M. A. ARBER said that she had listened with very great interest to Dr. Wilson's demonstration of the relation of cliff-form to structure in such exquisite detail; hitherto the published studies of cliff-profiles on this coast had been comparatively broad and generalised, and such precise and detailed work as that described, was most welcome. She was glad to find some of her own conclusions confirmed by Dr. Wilson and was especially interested in his having caught a hog's-back cliff actually in the making. In North Devon, the 'type-locality' of hog's-back cliffs, where the speaker had studied them most closely, she had found that they were either an escarpment or a dip-slope; here at Tintagel, a hog's-back was developing on a fault-plane, which from the sea's point of view was just as good to work upon as a dip-slope.

The speaker's first reaction to Professor Cotton's recent paper was some scepticism as to the 'two-cycle' hypothesis of cliff-development; she was more

inclined to agree with Mr. Challinor's interpretation that the bevel above was formed by sub-aerial erosion proceeding *pari passu* with the marine erosion which cut the vertical face below.

The speaker pointed out that in Willapark (at Tintagel, *not* the cliff of the same name at Boscastle), the sheer flat-topped face which Dr. Wilson had shown to be controlled by joint-planes, was on the western side and thus exposed to the greatest wave-attack. This was one of the many examples of the interplay of structure and erosion which Dr. Wilson had demonstrated and for which we should be grateful to him.

MR. R. N. BROTHERS drew attention to the fact that the marked absence of wave-cut platforms along the Tintagel coast may have some bearing on the controversy regarding the one-cycle or two-cycle nature of the coastal topography. If the present profile has been developed during one cycle then it seems that sub-aerial erosion, producing the 'back-slopes', and marine erosion, producing the steep cliffs, have progressed at equal rates. However, if it is believed that sub-aerial erosion is the speedier agent, one would expect to find shore-platforms—perhaps storm-wave platforms or even wave-cut nips—in abundance if the profile is a one-cycle product. In the absence of such features a two-cycle process, as outlined by Professor Cotton, seems to be indicated.

DR. W. G. V. BALCHIN has forwarded the following written contribution to the discussion:

Dr. Wilson's paper will I know be welcomed and fully appreciated by all those who are acquainted with the magnificent cliffed coast of the Tintagel district. This detailed study of some six miles of coast also throws fresh light on the fascinating problem of the evolution of the coastal morphology and coastline of south-west England—a topic to which increasing attention has been given in recent years.

With the facts at present available I do not see any serious divergence in the interpretation of Dr. Wilson and my own in the paper to which reference has been made. In this paper I generalised on a regional basis that there had been little change in the general location of the coastline throughout later Pleistocene and Recent time but allowed for local changes in the actual delineation and detailed morphology of the coast. ('So far as the minor indentations and delineations of the coastline are concerned a fairly intimate relationship between the structure and morphology can be demonstrated'—p. 337.) The section forming the subject of Dr. Wilson's admirable study is highly faulted, folded and jointed, and constitutes in many places zones of active erosion where there is a marked degree of correlation between the coastal morphology and the geology.

The hog's-backed cliff is, none the less, present: but as it is nowhere fronted by any raised beach-fragments it is not so easy to maintain its antiquity. Whilst the recent views of Professor Cotton on the possibility of a two-cycle origin for this type of cliff would seem to support the peri-glacial origin, which I put forward in 1946, I think that Dr. Wilson's paper is most important in that it does point to the possibility of this somewhat puzzling morphological feature occurring at any time in the evolution of the coast.

DR. GILBERT WILSON, in reply, thanked Miss Arber for her encouraging remarks. He agreed that so far as the normal processes of erosion were concerned any pronounced structural surface, whether it were a fault, bedding-plane, or joint, and provided it was inclined seawards, would tend to develop a sloping cliff-face. In the Tintagel area such structural guidance in one form or another played a large part in the evolution of the slope-over-wall cliffs. Nevertheless he fully realised that elsewhere there are stretches of cliff where the hog's-back form cannot be readily explained by invoking structural features. Of the two suggested processes put forward to account for the development of such cliffs—Challinor's combined sub-aerial and marine erosion, or Cotton's two-cycle process—the author prefers the latter as it appears to permit greater flexibility.

In reply to Mr. Brothers, the author pointed out that the sea-cliffs dropped directly into fairly deep water, and that the wave-cut platform which should be showing at the cliff-base was probably drowned by relatively recent submergence. Local wave-cut platforms are of limited extent, and there is no evidence except coincidence to prove that they are actually the products of present-day wave action.

Dr. Balchin's contribution to the discussion was very welcome, because it accentuates the difficulty of dating the cliffs. These are themselves composite and different parts of them differ in age, as is shown by the manner in which head-covered slopes or bevels are abruptly cut-off by more recent vertical cliffs, and elsewhere one slope may yield place laterally to another which is older or younger. Some upper slopes are smooth and present a youthful appearance, others are broken and irregular and suggest a greater age. These variations might easily be brought about by the development of the slope during different periods of sub-aerial erosion. The retreat of an initial slope-over-wall cliff parallel to itself, *and* the retention of its characteristic form, due to marine erosion only, necessitates a very delicate balance between the rate of retrogression resulting from wave activity below, and erosion by sub-aerial agencies above. The author agrees that the two-cycle process of erosion under alternating marine and peri-glacial sub-aerial conditions, seems to present the most simple explanation of the facts observed.

FIELD MEETING, WHITSUN 1951, AT TINTAGEL, NORTH CORNWALL

Report by the Director: Gilbert Wilson, Ph.D., F.G.S.

INTRODUCTION

THE Tintagel area of North Cornwall was last visited by the Association at Easter 1914, under the leadership of Mr. Henry Dewey, and the report of that excursion appeared in the PROCEEDINGS in 1915 (26, pp. 24–33). Much the same ground was covered by the present Field Meeting, but greater emphasis was laid on the structural details around Tintagel than on the former occasion.

By courtesy of the Council of the Geological Society of London, the twenty-five members attending were loaned galley proofs of the Director's unpublished paper on 'The Tectonics of the Tintagel Area, North Cornwall'. This provision was greatly appreciated by everyone present.

Friday (evening), 11 May

The party assembled at Tintagel, and at 8.15 p.m. the Director gave a talk, illustrated by a coloured 25in. to one mile map, on the geology of the area. Certain aspects of the structure outside the immediate area were briefly outlined, and the programme was discussed.

Saturday, 12 May

The party travelled by coach to Boscastle to commence a traverse southwards along the cliffs to Tintagel, across the strike of the Culm and Upper Devonian beds. Penally Head on the north side of the harbour inlet was first visited for the excellent exposures of contorted Culm beds (Plate 4A), which indicate a north-north-westerly sense of translation of upper beds over lower, i.e., down the gentle dip of the stratification.

After crossing to the south side of the drowned estuary of the River Valency to see further examples of zig-zag folding, the profile of Penally Point (Plate 2A, facing page 32) was discussed. It was remarked that the prominent 'nip' on the headland coincided with a horizontal quartz-vein, and it was decided that the feature was more probably the result of present-day storm-wave erosion than an indication of an earlier sea-level.

The structures showing on the walls of Eastern Blackapit were examined as the party followed the cliff path and the Director pointed out that the chasm was largely due to erosion along vertical joint-planes. Further folding of the Culm was seen near Western Blackapit, and the contact between these beds and the top of the Devonian

was observed near California Quarry. The same contact repeated by faulting was seen more clearly in the wall of Grower Gut.

The influence of inclined jointing and bedding planes in the development of hog's-back cliffs showed clearly from Boscastle Old Quarry (Fig. 5, page 31). Profiles due to inclined jointing may be seen towards the north, and those formed by dip-slopes can be observed by looking westerly. At Ladies' Window it was noted how flat projecting ledges of Tredorn Phyllites were etched by weathering on their *under* surfaces. In some cases holes had been eaten from below through beds two or three inches thick. This, it was suggested, might be due to the action of salt-spray or rain being driven violently up funnel-shaped gullies in the cliffs during storms. The drops would thus strike the undersides of projecting strata with a much higher velocity than could be achieved by rain falling vertically. An alternative suggestion put forward by the President (Mr. T. Eastwood) was that the circular hollows might be the result of solution by drops of water held by surface tension and hanging below the projecting surfaces.

From Ladies' Window southwards the main units of the Upper Devonian sequence were crossed in descending order. These are the Tredorn Phyllites, Trambley Cove Beds (at Trambley Cove), the Volcanic Series, now altered to chloritic schists, Barras Nose Beds, and the Woolgarden Phyllites. The Delabole Slates which lie below these last were not encountered on this day's traverse. The nine-inch band of creamy limestone, which occurs at the base of the Volcanic Series in a prominent exposure south-west of Trewethet Gut, was found to be fossiliferous, and Dr. Scott Simpson collected some unidentified planispiral shells, possibly cephalopods. Incipient boudinage structures in the same exposure were examined with interest (Wilson, G., 1951, fig. 3).

The path thence led down into Rocky Valley where pot-holes develop in the stream near its mouth, and several members recognised the scene as one of the better-known Geological Survey photographs (No. A864). When the party had climbed out of the valley, the position of the syncline of Barras Nose Beds between this locality and Bossiney was indicated. This fold may be accurately located on the track which leads from the main road at Bossiney village down to Bossiney Haven. Woolgarden Phyllites containing chloritoid were found lower down the same track in front of a small ruined hut.

The plunging nose of the Davidstow Anticline was crossed along the cliff-path above Bossiney Haven to Willapark. From the latter the relationship of the inclined jointing to the hog's-back cliff could be seen in the face and profile of Lye Rock; and on Willapark itself evidence of incipient rock-falls was noted at the top of the vertical south-west face of the promontory. Some members descended the steep grass-slope below Willapark towards Gullastem to see the normal step-faulting which cuts the Tredorn Phyllites and the under-



A.—CONTORTED CULM BEDS, PENALLY POINT, BOSCASTLE



B.—DRAG-FOLDS ASSOCIATED WITH NORMAL FAULTING,
TINTAGEL.

[To face p. 50.

lying Trambly Cove Beds. The unsheared epidiorite at the east end of Smith's Cliff was then examined and a return was made to Headquarters.

Sunday, 13 May

The traverse recommenced at the east end of Smith's Cliff. After a brief explanation had been made of the manner in which the epidiorite and Woolgarden Phyllites had been thrust over the Volcanic Series and Trambly Cove Beds, the party descended to the foot of the cliff, noting features indicative of normal faults throwing down towards the west, and the manner in which the epidiorite became more and more sheared as the bottom of the cliff was approached. A gouge-filled normal-fault fracture was exposed just above sea-level in the re-entrant. As recent rock-falls had occurred hereabouts the party was not permitted to linger, and were hurried around the cliff corner westwards on to the broad ledge of sheared volcanic rocks which forms the sole of the 'Flat Thrust' (T_1). The ledge is within reach of storm-waves which have eroded the actual thrust-zone into a thin horizontal saw-cut. Cleavage within the thrust-zone, slicken-sides, elongation of spots, and the orientations of tension-cracks showed that the upper rocks had moved north-north-westerly relatively to those below. The welded contact of the epidiorite sheet with the overlying Woolgarden Phyllites was observed in the craggy slopes immediately west of two big epidiorite boulders between which the party had to climb one at a time. Thence it became impracticable to follow the thrust further, and the party scrambled up a steep grass-slope to rejoin the cliff-path.

Numerous examples of marine erosion along joints were noted west of Smith's Cliff, and the importance of normal fault-zones in guiding wave-attack was pointed out in East and West Barras Gugs. Near the latter the conformable succession of Barras Nose Beds above the Woolgarden Phyllites of the Tintagel Thrust Unit was observed on the top of a small rise. A descent was thence made down the grass-slope at the north-east corner of Barras Nose to see the thrust (T_2) which brings the Barras Nose Unit with Woolgarden Phyllites at the base, on top of sheared Volcanic Series of the Tintagel Unit. The cleanly-cut nature of this thrust aroused considerable comment, and the lack of shattering seen here was contrasted with the crush-zone of the Flat Thrust (T_1).

From the path between Barras Nose and the east side of Tintagel Haven, the importance of normal faulting was demonstrated. The trend of the Caves Fault Zone from West Barras Gully, under Blacka-rock peninsula and across the Haven to form the great shear-zone, which runs diagonally up the cliffs of the Island (Wilson, G., 1951, pl. 30), was clearly seen. The sloping face of the hillside here is largely formed by gently inclined fault-planes which are the up-dip continuation of the Caves Fault Zone (Plate 3A, facing page 36). Barras Nose

Beds strongly contorted by down-dip movements and forming the hanging-wall rocks of these faults may be seen near the top of the slope to the west of the Castle Hotel (Plate 4B). The party then turned into the Trevena Valley and saw the line of the Castle Fault which, to the north of the stream, is well marked on the valley side. The formation of the 'Trevena Window', as a result of the stream cutting down through the Flat Thrust (T_1) into the Foundation Unit below, was demonstrated while walking up the valley; below the thrust is a prominent line of Trambley Cove exposures; above it is the 'Window Frame' of sheared epidiorite and Woolgarden Phyllites.

Because of the state of the tide it was decided to visit Trebarwith Strand that afternoon instead of continuing investigations around Tintagel. The party therefore walked southwards along the cliffs above the old quarries in the Delabole Slates of the Tintagel Thrust Unit. At the top of Lill Cove some good, but distorted, specimens of *Spirifer verneuili* were found in a little excavation in the Tredorn Phyllites. The Lill Cove thrust-zone (Wilson, G., 1951, pl. 29, fig. 1) was then visited by traversing horizontally for a few yards across the top of the grass-slope in the north-east corner of the re-entrant. The evidence of the north-north-westerly thrust-movement presented here was acknowledged by all. The party then descended into Trebarwith Strand, and, while waiting for the tide to retreat further, followed the road into Port William to note the normal faults which cut the cliffs of Dennis Point, and their influence on the development of slope-over-wall cliffs (Fig. 1).

As the tide fell it became practicable to work northwards along the beach. Deformed lava-fragments or pillows in the rocks were examined at several localities, and their directions of elongation and the orientations of joints in the less plastic inclusions of the sheared volcanic rocks were shown to be in conformity with the general north-north-westerly movement. Below Lill Cove the Director pointed out the longitudinal edge of a partly exposed boudin in the cliff-face. North of Veian Hole the Flat Thrust (T_1) was seen in the cliffs, and the prominent zone of boudinage structure, which lies below it, was examined with interest (Wilson, G., 1951, pl. 29, fig. 2). The tide did not allow the party to reach Hole Beach where the Thrust can be examined on the shore, so a return was made to Tintagel via Treknow. This enabled members to see once again the general succession of the Foundation rocks in the Trebarwith Valley. Boudinage structure and drag-folding were also seen in the old quarry and road cutting at the top of Treknow Hill.

Monday, 14 May

The morning was spent in Tintagel Haven and on the Island. Small-scale structures—tension-gashes, cleavage, drag-folding, etc.—associated with the normal faulting movements were demonstrated

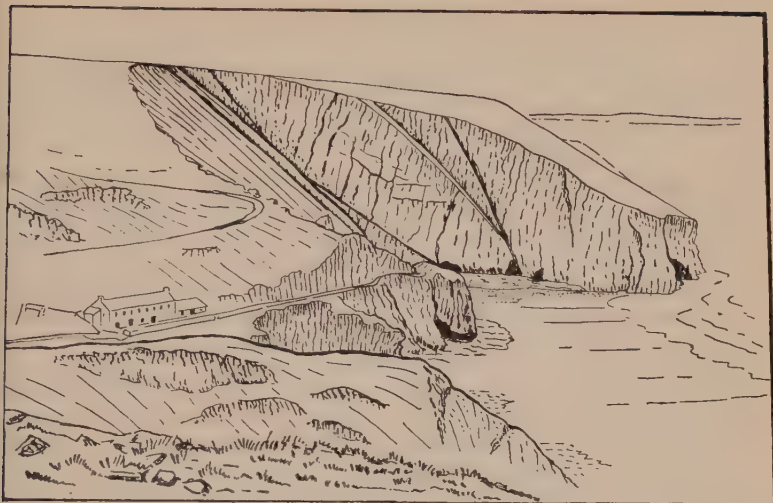


FIG. 1.—Normal Faults on Dennis Point seen from the top of Lill Cove. (Drawn from a photograph).

on the Haven cliff near Merlin's Cave, but as the tide was high, it was impossible to pass through the Cave into West Cove. The structure of that Cove was therefore explained by the Director from the Castle on the Island; he stated that the present shape and the forms of the cliffs surrounding it were due to erosion undercutting the hanging-wall rocks of the Castle Fault, and that these rocks had broken away along the inclined fault-plane on one side, and along vertical joints on the other (Plate 3B, facing page 36). Other fault zones, such as that in Merlin's Cave, had also been attacked by the waves. While some members examined the Castle ruins others descended to the Iron Gate where the rock-sequence seen on Barras Nose crosses the Haven and can be picked up again on the Island. The general line of the thrust (T_3) between the Volcanic Series of the Barras Nose Unit below, and the overlying phyllites which form the main mass of the Island, was also indicated. Comment was made on the manner in which the phyllites west of the Castle undulate in wide gentle folds. The westerly regional dip does not show here, and the central part of the flat-topped plateau, which is partly covered by head, is synclinal in character. A rainwater catchment-area has thus originated, in the centre of which the Castle's well had been sunk.

After leaving the Island the party ascended from the narrow isthmus to the Outer Wards of the Castle situated on the mainland. While the long flight of steps was being climbed, attention was drawn to the normal fault-planes which locally coincide with the slope of the hillside. Drag-folding and boudinage structures were

both studied in the rock-face beside the Castle gateway (Wilson, G., 1951, fig. 9, p. 412). The top of the Castle Fault, with which is associated a plexus of quartz-veins, was also examined. From this point, on looking down the great slope into West Cove, it was clearly seen how the dislocation had been utilised by the wave-attack which had excavated the Cove.

The contact between the epidiorite and the Woolgarden Phyllites was studied near the Castle gateway. About fifty yards south of the Castle sheared epidiorite and overlying spotted Woolgarden Phyllites are exposed; the orientation of the elliptical spots in the phyllite was observed, and numerous specimens were collected. Similar rocks had also been seen on the beach of Tintagel Haven beside the Waterfall, and, by comparing the difference in level between the two exposures, the throw of the intervening faulting was estimated as approximately 250ft. towards the north-west.

After luncheon the party were conveyed by coach to Roughton on the Bodmin Granite. The route crossed Slaughterbridge, near Camelford, where the soft phyllites exposed by the roadside were pointed out as belonging to the lowest group of the Upper Devonian strata known in this area—the Slaughterbridge Beds. They lie stratigraphically below the Delabole Slates. The coach stopped at Roughton Farm where Mr. C. E. Leese (of Camelford) introduced the owner, Mr. A. W. Patten, to the members. Mr. Patten was then invited to give a talk on his experiences in counteracting mineral deficiencies in pastures situated on the granite. He stated that it had long been realised that sheep and cattle (but not horses) could not be grazed continuously on the local granite-soil without contracting 'moorsickness' or 'pine', which leads to rapid loss of weight and death; and, in order to keep the animals healthy, they had to be pastured periodically on killas or slate country for a while. Even sheep in the last stages of collapse would recover if they were carried down from the moor to the other pastures. Investigations indicated that the disease was due to cobalt deficiency in the granite-soil, and experiments were conducted, as they had been in New Zealand, to see if this could be counteracted. This was first done by dosing (or drenching) once a week with a weak solution of cobalt chloride (7 mg. per head). Lambs so treated rapidly put on weight, even though they were not removed from the granite pasture-land. Twenty untreated lambs were kept as a control on the same grazing; of these nineteen died. Such treatment is impracticable with large numbers, so the pastures themselves are now dressed with cobalt salts which are extracted from the soil by the growing vegetation. The animals thus take in the cobalt as they feed. Mr. Patten showed photographs of lambs fed on treated and untreated pastures, which clearly demonstrated the success that he had achieved. The President thanked Mr. Patten for his most interesting talk and congratulated him on the results of his investigations.

The party then walked to the foot of Roughtor where they were met by Miss Dorothy Dudley, who had most kindly come from excavations farther south on the moor to conduct the party around the 'Hut-Circles' which lie on the north-west slope of the Tor. Miss Dudley explained that she is excavating in three neighbouring sites of hut-circles with which are associated field-systems. Her excavations so far are not conclusive in this area, and as no pottery has as yet been found, a definite age cannot be assigned to the constructions, which possibly range from the Bronze Age to Medieval times. Miss Dudley pointed out that there were two types of hut-circle present. The first consists of huts 12ft. to 20ft. in diameter, with fireplaces, saddle-querns, fire-cracked stones, and some flints. The second type is larger, 30ft. to 40ft. in diameter, with well-made walls. It is with such huts that the Celtic field-systems are linked. Miss Dudley also indicated two ancient earthworks or defensive lines on both sides of the summit-ridge of Roughtor. The party then ascended to the top of the Tor, where they looked at the view, investigated rock-basins hollowed into the upper surfaces of the granite-blocks, or discussed the good examples of tor-weathering.

On the return journey Mr. Leese took the party to an exposure at Greylake of the long quartz-porphyry or elvan dyke which runs roughly parallel to the edge of the Bodmin Granite. Some specimens showed little rosettes of tourmaline. In the same general locality fragments of silvery andalusite- and spotted-schists were picked up. Thence, after thanks had been expressed to Mr. Leese for his helpful co-operation, a return was made to Tintagel.

Tuesday, 15 May

On this day it had been arranged to visit the Old Delabole Slate Quarry, Helsbury road-stone quarry and Pentire Head. At Delabole the party was met by Mr. Joe Setchell and Mr. J. A. Kent, Directors of the Old Delabole Slate Co. Ltd.; and the general setting of the quarry was then explained by Mr. Setchell. The original quarries were working in the reign of Queen Elizabeth I, and were sited on the sides of a valley which drained southwards. This hollow is now largely buried beneath great dumps of waste upon which stand the present-day quarry-buildings. The excavation is a roughly D-shaped hole some 500ft. deep, and a mile in circumference. The straight western edge is determined by a north-south zone of tear-faulting which dips steeply to the west and is known as 'The Clay Lode' because of its gouge-filled character. This fault brings Delabole Slates of the quarry on the east against valueless phyllites (probably Tredorn) on the west. The northern end of the quarry cannot be extended because of the local railway; so activity is at present towards the east. The dip is westerly at about 15°, bedding is difficult to identify, but in weathered sawn blocks it can often be seen lying at 10-15° to the cleavage.

Usually bedding can only be recognised in the field where rare thin grit-bands occur. These are commonly discontinuous having been wrenched apart during the tectonic movements. In the bottom of the quarry such a grit-band shows a sharp recumbent isoclinal fold closing downwards to the west and plunging south-south-westerly at about 8° with its axial plane parallel to the slaty cleavage. The slate-belt is crossed by faults of various trends. Those which are parallel to the main north-south Clay Lode, are usually referred to by the same term because they too contain clay gouge. Others of similar strike, which dip eastwards, are called 'shorters', and are cleanly cut fractures without gouge. Steeply-dipping minor dislocations called 'ratchets' trend at right-angles to the grain of the slate, and are of assistance in the extraction of slate-blocks. They cut across all the other structures in the quarry, including several inclined fault-planes which dip northerly and westerly.

The party were then loaded into two quarry-cars and lowered down one of the steep inclines to a bench about half-way down where a working face was examined. Thence they were taken to see a good dip-section of shorter and clay-lode faulting in the south face of the quarry. Here also is an ancient drainage tunnel about half a mile long beneath the level of the original valley floor. It had been driven along a clay-lode fault and is still in use. During the descent to the bottom of the quarry there was considerable discussion on the subject of 'cats'-paws'. These are occasional buff or pale brown dolomitic blotches in the slate. They are paper-thin, and may be roughly rounded or elliptical in outline; where marked elongation of a 'cats'-paw' is observed, it is found to be parallel to the grain of the slate. This, and their similarity to phenomena observed elsewhere, led the President to conclude that they were squeezed and drawn-out concretions.

When the tour around the quarry had been completed, the dressing sheds were visited. Here the slate-blocks are cut by circular saws armed with diamonds, and are then split by hand into roofing slates. Large slabs are mechanically planed and smoothed for tombstones, stone shelves, etc. Good grade slate which is unsuitable for splitting is crushed and ground to make slate-powders used as fillers in asphalt, roofing-felt, paper, plastics, etc. The powders are air-elutriated and the finest has a grade-size of which ninety-five per cent of the product is less than 10μ in diameter.

At noon, after the President and Director had thanked Mr. Setchell and Mr. Kent for their courtesy and kindness, the party went on to the Helsbury Quarry which lies due east of the village of Michaelstow on the Camelford-Bodmin road. The quarry is worked by the County Council of Cornwall for road-metal, and permission to visit it had been kindly granted by Mr. E. H. Collicutt, O.B.E., the County Surveyor. The quarry is divided by the entry-road; the northern section is recent, and the southern section, which is deeper, is

older. Both sections were visited. The rock quarried is shown on the 1-inch geological Sheet No. 336, as a narrow north-south intrusion of diabase, dipping, according to the map-section, west at about 45° . The mass lies within the metamorphic aureole of the Bodmin Granite, and is formed of a hard tough rock, unlike many of the unmetamorphosed greenstone intrusions of South-west England. It is coarse in texture and in the hand-specimen resembles a gabbro.

Beneath the microscope the rock is seen to consist of large crystal aggregates of fibrous, pale green amphibole (actinolite), some chlorite which gives ultra-blue polarisation colours, and sphene, all embedded in a finer grained groundmass of altered felspar. The groundmass felspars are crowded with finely granular zoisite and little flakes of actinolite. The shapes of the plagioclase crystals can be faintly distinguished, but the best evidence of original texture is presented by their relationship to the sphene. This mineral occurs as crystals up to 5 mm. across, and poikilitically encloses lath-shaped inclusions of altered felspar. In a few cases the latter are still represented by individual plagioclases. The shape of the inclusions and their relationship to their host-mineral are indicative of an earlier doleritic texture in the rock, now lost in its alteration to epidiorite. The present coarsely crystalline appearance of the rock is not original and is mainly due to the development of amphiboles during recrystallisation.

Mr. Leese, who was kindly acting as guide, pointed out the sediments which underlie the sheet-like intrusion on the north-east side of the excavation. These contain fossils and several specimens in rather poor state of preservation were found. The igneous mass above these sediments is much broken by crush-zones containing laminated gouge. Felspathic, epidotic and garnet-bearing veins occur in the rock and some interesting specimens were collected. Recently, while stripping the overburden from this quarry, the workmen found a little group of flints, each of which was broken as if it had been chipped for flakes. In the old southern section of the quarry attention was drawn to the depth of weathering, which reaches 20ft. in places, penetrating down joint-planes and shear-zones, and thus enclosing large weathered boulders in reddish-brown clay.

From Helsbury Quarry the party was conveyed to the lane leading to Pentire Point with its great sea-cliffs mainly composed of pillow-lava. Several exposures, including those illustrated by Dewey in the PROCEEDINGS (1914) and in the South-West of England, Regional Guide, were seen. After a brief visit to the extreme end of the Point, where dolerite-sheets cut sheared black slates, a return was made to the coach. Here the President proposed a vote of thanks to the Director, who, he also mentioned, had acted as Field Secretary for the Meeting. The party then returned to Tintagel.

EXPLANATION OF PLATE 4

A.—Contorted Culm Beds, Penally Head, Boscastle. The zig-zag folds were formed by a movement of the upper beds towards the left (north-north-easterly) relative to the lower beds. The axial planes are nearly horizontal.

- B.—Drag-folds in Barras Nose Beds associated with normal faulting, west of the Castle Hotel, Tintagel. The folded beds form the hanging-wall of the faults which can be seen on the right-hand side of the plate. Quartz-filled fractures show up white against the dark Barras Nose Beds.

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FIELD MEETING IN THE CENTRAL CHILTERNS

7 May 1949

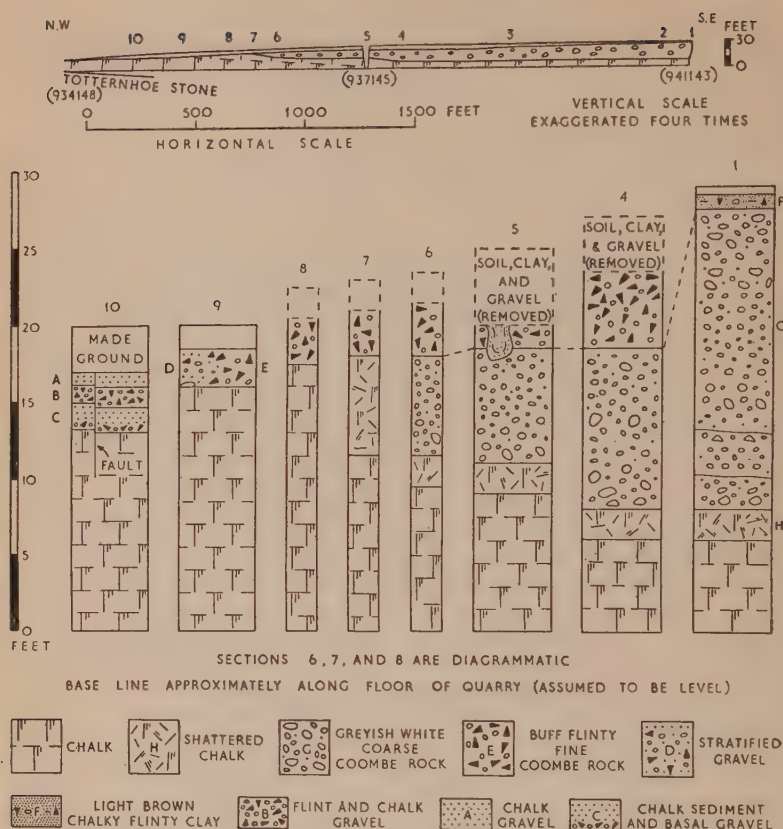
Report by the Director and Secretary: P. Evans, M.A., F.G.S., and
K. P. Oakley, Ph.D., F.G.S.

[Received 1 November 1951]

MEMBERS travelled from Wendover by coach along the Icknield Way, noting, in passing, the Melbourn Rock platform below the steep slope capped by the Upper Chalk. North of Folly Farm (941141) in the large chalk pit, visited by kind permission of the Tunnel Cement Co. (Pitstone) Ltd., sections were seen showing the Totternhoe Stone and overlying *Holaster subglobosus* Zone of the Lower Chalk. This is grey and marly in the lower part, but purer, greyish-white and more blocky above. These beds are moderately fossiliferous, and a number of ammonites (including *Acanthoceras*) were found by members. Of much more interest are the overlying Pleistocene deposits, which have not hitherto been described.

At the south-western end of the pit the chalk is overlain by about twenty feet of greyish-white coombe rock consisting of large and small blocks of chalk in a matrix of fragments of chalk from the size of peas down to fine powder. At the south-eastern end of the pit (point 1, Fig. 1) the coombe rock (G) consists of sub-angular lumps of chalk, averaging about two inches across, embedded in a matrix of chalk-powder, pea-sized fragments being much rarer. The larger blocks here are about eight inches across, but farther north blocks up to two feet across may be seen. Some of the large blocks appear to be of Melbourn Rock. The coombe rock shows impersistent lines with a slight inclination. The chalk below the coombe rock is shattered for about two feet (H); there is consequently no sharp junction between the coombe rock and the undisturbed chalk. The underlying chalk rises north-eastwards and the lower part of the coarse coombe rock (G) is replaced by disturbed chalk which gradually passes into normal chalk (6, 7, 8).

At the top of the section, resting on an irregular surface of the coombe rock (G), is a thin band of light brown chalky clay (F) with angular flint fragments and small chalk pellets. This is overlain by a thin covering of dark brown clayey soil with numerous flints. A short distance northwards (point 2) the light brown flinty and chalky clay is festooned down into the coombe rock (G), and farther north it thickens; still farther north, about 3, bed F gradually passes into a fine, buff-coloured coombe rock (E) consisting of small angular and sub-angular flints and small fragments and pebbles of chalk with some chalky matrix. Some of the broken flints are fresh grey, others are brown and patinated, derived from a previously weathered surface.



At point 9, towards the northern end of the cutting leading from the quarry to the cement works, this fine coombe rock passes laterally into stratified gravel (D). This shows much variation but a measured section (10) gave, below 'made ground':

- A. 1 ft. of fine, cream-coloured, flintless gravel consisting of small sub-angular chalk pebbles (up to $\frac{1}{4}$ in. diameter) in a chalky matrix.
- B. $1\frac{1}{2}$ ft. of coarser brownish gravel consisting of angular splintered pieces of flint, up to an inch in length, together with sub-angular and rounded chalk fragments ($\frac{1}{8}$ in. to $\frac{1}{4}$ in.) in a scanty matrix of powdered chalk.
- C. $1\frac{3}{4}$ ft. of fine, nearly white sediment consisting almost entirely of powdered chalk. This grades down into a basal gravel similar to the overlying bed, but only a few inches thick.

At this measured section a small fault with a throw of three inches can be identified in this deposit and traced for at least four feet down

into the chalk below, the fault-plane being marked by traces of gravel. The deposit shows impersistent lines of iron pan. In general the fine beds occur as lenses within the coarser beds.

For some distance northwards from point 2 there are a number of festoons of darker material in the coombe rock; this includes brown clay with broken flints and the fine flinty coombe rock of beds F and E. Near point 5 (where a track runs down to the quarry) the vertical sections show festoons to a depth of almost four feet, with an amplitude of one to two feet. Clearing of the overburden has here revealed in plan several well-formed frost polygons exceeding three feet across.

On the western face of the quarry there are good sections showing at the northern end about six feet of very flinty fine coombe rock overlying the coarse coombe rock. Brown clay with numerous flints occupies large festoons in the fine, pale brown or buff coombe rock. Farther south on this face, similar festoons are well seen in the upper part of the coarse greyish-white coombe rock. These have been slightly disturbed or pulled by later flow of the coombe rock.

The sequence of events seems to have been as follows. During a period of intensely cold winters broken by short possibly fairly hot summers, the chalk from the lower parts of the adjacent scarp was broken up and flowed gradually northwards. This solifluxion did not carry down to this area any great thickness of the chalk above the Melbourn Rock. A later solifluxion brought down a sludge of chalk with a large number of flint fragments. This seems to have reached a flooded area, possibly the margin of a lake held up by the glacier of the Vale of Aylesbury, and there to have formed the stratified deposits of chalk-powder and chalky gravel seen at the northern end of the cutting; the layer of chalk-powder suggests deposition on a lake bed. The spread of poorly stratified chalky gravel on the floor of the Vale at Gubblecote (906150) (Oakley, K. P., 1936) was probably formed at this time. Still later there was brought into the area a thin bed of flinty clay which was subjected to arctic temperatures leading to festooning and the formation of frost-polygons.

After detailed inspection of these Pleistocene deposits the party paid a brief visit to the quarry (948148) about 600 yards ESE. of Pitstone church which provides sections slightly higher in the succession. Belemnite Marl (*Actinocamax plenus* marl) and the overlying Melbourn Rock were seen to dip appreciably to the south-east and to be slightly disturbed by minor faulting.

After lunch members inspected Coombe Hole (967174) and Incombe Hole (959156), two typical scarp valleys, the latter showing clearly the sharp right-angled bends so well seen in the Hexton valleys. The Director mentioned various hypotheses put forward to account for these deep narrow valleys, and a discussion followed in which Dr. A. J. Bull, Dr. Oakley, and other members took part. From Ivinghoe Beacon (960168) it was possible to get a view across

the clay vale to the Lower Greensand beyond. On the way back to Wendover the opportunity was taken to get views over the Pliocene marine bench at about 650 feet above sea-level and of the higher ground to the north which was not submerged during the Pliocene transgression. After tea, which was taken at Tring, the thanks of the party were given to the Director and Secretary.

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SOME ASPECTS OF THE DEVELOPMENT OF THE LOWER STOUR, KENT

By Alice Coleman, M.A.

[Received 4 July 1950]

[Read 6 July 1951]

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SUMMARY.—During two years' field investigation in East Kent the terraces of the Lower Stour have been mapped in detail, and their height-ranges established by aneroid survey. Ten terraces form a staircase thirteen miles wide, indicative of a persistent easterly migration. The cause of this migration is believed to be a secular tilting towards the North Sea. An alternative explanation of structural control is rejected on the evidence of a map of the Eocene base which incorporates new data from the Geological Survey's war-time Water Supply Pamphlets. Certain relevant features of the terrace gravels are described. Correlation with other areas is attempted and the old sea levels of the South Downs are found to be consistently higher than corresponding Stour terraces. Morphological records which would facilitate future correlation are indicated.

1. INTRODUCTION

THE most easterly mass of the London Clay in Kent is the wide and partly gravel-capped tract of "the Blean", bounded on the west by the fine wooded escarpment above Herne Hill and Boughton-under-Blean, on the south by the valley of the Stour, on the east by that of the Wantsome Channel, and on the north by the sea.'

With these words, in 1872, W. Whitaker defined the compact sub-region of East Kent which is the concern of this paper. After his

mapping of the area in 1868, and his description of it in the London Basin Memoir, there was no further work on the Blean¹ until 1923 when I. Collins and D. M. C. Gill carried out a detailed investigation of the structure and lithology of the western margin. Two years later a paper by H. Dewey and others on 'The Geology of the Canterbury District' again took the whole Blean into its scope, though it still concentrated, like the earlier writings, on the more diversified Lower London Tertiaries of the borders. An account was included of Dr. Ince's work on the palaeolithic gravels at Sturry in the Stour Valley, and the section by S. W. Wooldridge laid the first foundations of the denudation chronology of the Stour. Wooldridge noted terrace fragments in the Stour gap, relating to a 200-ft. erosion stage which he and J. F. Kirkaldy afterwards traced downstream into the Blean, where it was associated with two lower Stour terraces, at 150 ft. and 100 ft. This later work was never published in full, but the resultant map was used by R. A. Smith in 1933, in a paper on the palaeolithic gravels at Fordwich, south of the Stour. The present study broadly confirms these three stages, which have now been mapped in detail, demonstrates that one of them is dual, and reveals the existence of six, or possibly seven, further terraces between the present flood-plain and the culmination of the Blean at 400 ft. It indicates also that the highest surface is not an extension of the Pliocene marine platform as was tentatively suggested by Wooldridge in 1927, but is a rather later river terrace of the Stour.

Only a few of the papers mentioned above are directly concerned with geomorphology, and their treatment, though valuable, is far from being exhaustive. Moreover, it is nearly twenty years since any field work was done in the area, and this is an interval which has seen a great advance in our general knowledge of the physiographic evolution of South-east England. In addition, the late J. F. N. Green's conception of detailed morphological survey on the six-inch scale has substantially increased the precision that may be expected from field investigation. The morphological map is a document which supplements ordinary geological mapping in various important respects. Morphological features can be observed and measured in the absence of open sections, and they yield evidence which can be obtained in no other way. A complete survey of the Blean by such methods has been attempted.

2. FIELD TECHNIQUE

The aim of this work has been to cover the Blean with a close field scrutiny, and to map, on the six-inch scale, any flat surfaces or other features which might illuminate the denudation chronology of the region. Three hundred such surfaces, or 'flats', have been discovered and mapped in detail, the levels of their front and back edges being

¹ Reference to Starkie Gardner's description of the Herne Bay coast section (1883), which hardly concerns the subject of this paper, is excluded.

determined to establish their height-ranges. The technique adopted was the aneroid method proposed and successfully used by B. W. Sparks (1949), who claims it is accurate to within five feet.

A 'flat', in the morphological sense, cannot, of course, be geodetically level, and is generally held to be a surface which is marked off by definite breaks of slope from steeper surfaces behind and in front of it. By this definition, terrace or bench features may actually be visibly sloping at 1° or more, and still qualify as 'flats', by virtue, not of angular measurement, but of morphological relationship. Surfaces of this nature normally present little difficulty in field mapping. In the Blean, however, an unusually low gradient characterises the bluffs as well as the terraces, making it difficult to separate them. The bluffs frequently slope at less than 1° ; they are thus flatter than many true flats in other districts. But if mapped as flats they become incorporated into terraces as much as six miles wide and up to 120 ft. in transverse height range. It was essential to attempt a subdivision of such comprehensive surfaces, and this has in fact proved possible. Slight breaks of slope are recognisable, and occur consistently at the same level.

It was also necessary to determine the nature and origin of the mapped surfaces, and to this end attention was given to their drift-cover. The inquiry was designed to supplement the information already provided on the one-inch geological map. This latter information is incorporated into Fig. 3 where proved thicknesses of over 3 ft. are distinguished from surface indications, of which the thickness is unknown. Fluvial gravels consistently underlie the 100-ft. surfaces, and are associated in places with each of the others.

Their patchy distribution is a little difficult to interpret, but in the light of the morphological evidence, it appears that the surfaces were in fact formed as normal terraces of the Stour. If gravel was once continuous on each surface, it has subsequently been stripped by normal subaerial processes, particularly from the London Clay, as greater thicknesses have been preserved on the Lower London Tertiaries of the South-west. A further possibility is that the drift deposited upon the clay-tract was originally mainly alluvial, with occasional pockets of gravel. If so, it may still be present as the ubiquitous 'stony soil' which is very similar to the London Clay itself, and is normally mapped as such. This latter interpretation presents fewer difficulties regarding terrace levels, but the former possibility (that of gravel removal) must not be overlooked. In this case the problem arises of how to effect a valid height comparison of surfaces which may at one place be truly 'terminal' (the original depositional surface of the gravel sheet), and at another 'basal' (the original erosional surface beneath the gravel). Intermediate levels due to partial removal complicate the issue still further. In such circumstances definite height discrepancies within each stage might be expected. The paradox of the Blean is the absence of such discrepancies

and the firm internal consistency of the 'terrace levels'. In fact, the aneroid evidence can only be reconciled with the drift evidence if it is assumed that any terrace gravels were never very thick, and that their removal, or partial removal, has caused a lowering of only a few feet. The error introduced in regarding each surface, within fairly close limits, as representing a former level of river-action, i.e., as in effect, a terrace, could not be great if the original gravels were thin, and since the flats mapped are well-marked, showing clearly a consistency in height, it is difficult to avoid the conclusion that they do afford evidence of a series of stages of downcutting.

3. GEOMORPHOLOGICAL RESULTS

The essential morphological pattern revealed by the mapping is simple. This pattern is clearly seen if minor details are ignored and attention is focused upon only the main flats above 100 ft. The term 'main flat' is used here in a precise sense for those surfaces created by the Stour itself, as distinct from those formed by its tributaries. They are numbered one to sixty-seven in Fig. 1. They are all sited on the major interfluves and fall into clear natural groupings on the basis of height. They run in series from south to north. The highest member is in the west; progressively lower surfaces¹ succeed it eastward. They form, therefore, a broad morphological staircase of which the nature is best demonstrated by means of a section drawn across the southern Blean (Fig. 2). This section follows the crest of the spur south of the Sarre Penn; on this all the stages are represented.

When this sequence of stages is considered as a whole, it is possible both to perceive a reason for limited gravel accumulations in the Blean area and also to explain the much greater thicknesses exposed near Chartham Hatch. The arrangement of the terraces clearly denotes an easterly migration of the river. The earliest and highest surface runs northward in direct alignment with the Wye gap and may be regarded as marking the line of an early simply 'consequent' course. Subsequently the Middle Stour cut down *in situ* through chalk without any appreciable lateral migration, but the Lower Stour which flowed across Eocene country, moved largely and freely eastward, thus initiating the great bend at Chilham and forming the successive treads of the main terrace flight. A river that was thus actively migrating was likely to spread its gravels widely in space as distinct from piling them up cumulatively at or near the one spot. This latter condition was more nearly realised near what may be termed the 'hinge' of the migration, i.e., near Chartham Hatch. In this vicinity, therefore, greater thicknesses of gravel are to be expected, and are, in fact, present.

¹ In the attempt to use a simple and definitive nomenclature the term 'flat' is employed throughout for the actual fragment of surface mapped, and the term 'surface' for the reconstructed whole at any one stage.



FIG. 1.—FLAT SURFACES IN THE BLEAN. (Reduced from the six-inch scale.) 1: High 5: 205-ft. Stage; 6: 160-ft. Stage; 7: 125-ft. Stage; 8: 100-ft. Stage; 9: Upper Reculver mate points where the Stour crossed the present coastline towards the end of each St



1 Blean Stage; 2: 350-ft. Stage; 3: 300-ft. Stage; 4: 265-ft. Stage; Stage. 10: Lower Reculver Stage; 11: Flood-plain; 12: The approxi-
 age; 13: Bluffs. Flats left blank are those beyond the scope of this paper.

[To face p. 66.

The transverse height-range of each of the surfaces has been measured at its northern or seaward end, and is set out, to the nearest five feet, in the following table.

1st Surface	...	...	...	Back of Surface	Front or Riverward Edge
2nd	"	...	...	?	c. 356 ft.
3rd	"	...	...	360 ft.	350 ft.
4th	"	...	...	330 ft.	300 ft.
5th	"	...	...	285 ft.	265 ft.
6th	"	...	...	240 ft.	205 ft.
7th	"	...	...	180 ft.	160 ft.
	"	...	...	145 ft.	100 ft.

The lower figure is in each case the nearest approach to the contemporary sea level, and is the designation used in the sequel.

The front and back heights of each individual flat have been used to prepare a height-range diagram, which includes all the main flats above 100 ft. (Fig. 3). Heights are represented vertically and plotted against the north-south range of the flats. The diagram merely confirms the evidence of the map, indicating a slight though clear separation of the various levels.

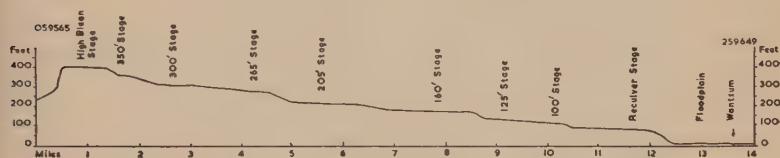


FIG. 2.—SECTION THROUGH THE TERRACE-FLIGHT OF THE STOUR. The section-line runs ENE. along the crest of a spur. The vertical scale is 21.2 times the horizontal.

(a) Longitudinal gradient of the terraces

The partial removal of gravel combines with the limited north-south extent of the surfaces in rendering it difficult to establish the longitudinal gradient where the fall is only slight. Five of the terraces are in this case. They are the 100 ft., 160 ft., 265 ft., 300 ft., and 350 ft. It is not known how far beyond the present coast the former river mouths lay, but they cannot have been far removed from these very gently declining terrace tracts. These epicycles were clearly brought into being in response to stable levels of the sea at successively lower elevations. The concept of a falling sea level punctuated by still-stands is a theme now too familiar in south-east England to require any elaboration.

The 205-ft. terrace has an appreciable fall (5 ft. per mile). This was evidently formed at a time when the mouth of the river was at some distance from the present north coast.

The highest surface shows the markedly stronger rate of decline of 20 ft. per mile. It rapidly descends from 407 ft. to the level of the

350-ft. terrace, which appears in consequence to merge into the higher one northward at Holly Hill. The Holly Hill flat (No. 65 in Fig. 1) lies at 356-360 ft., and could equally well belong to either stage. Thus the highest surface of the Blean cannot be given a satisfactory height designation and is termed the High Blean stage. The gradient is so steep that it seems unlikely in any case that it is an original river gradient.

(b) Transverse gradient of the terraces

Measurement of the transverse gradients has been assisted by the persistent easterly migration of the stream. Migration during as well as between the successive stages, has caused a broadening of the terraces themselves, and imposed a generally wide and gentle slope upon the intervening bluffs. The river seems constantly to have attacked its right bank: these left-bank terraces bear no sign of ever having been undercut. They probably retain, therefore, substantially their original breadth. In the case of the 100-ft. and 200-ft. stages, this is as much as two miles, and the other terraces also are broad enough for the computation of transverse gradient. The following figures are the averages for the different stages:

Highest surface	...	...	...	...	33 ft. per mile
350 ft.	...	...	...	...	30 " " "
300 ft.	...	...	...	...	29 " " "
265 ft.	...	...	...	...	21 " " "
205 ft.	...	...	...	...	16 " " "
160 ft.	...	...	...	...	15 " " "
100 ft.	...	...	...	...	22 " " "

Thus, in contrast with the longitudinal profiles, the transverse fall is marked. In each instance it is conspicuously greater than that of the modern flood-plain which is certainly less than 5 ft. per mile. This latter disparity is partially explained by the contrasted origins in the two cases. The flood-plain, on the one hand, resulted from silting of a recently drowned estuary; the terraces, on the other, were cut-and-built features. Nevertheless a certain difficulty still attaches to the magnitude of the terrace-gradients. There is clearly no correlation, terrace for terrace, between the longitudinal and transverse rates of decline. With the single exception of the 100-ft. terrace the trend revealed here is an increase of gradient with age, and even the exception is found upon closer examination to be more conformable to the general trend than at first appears, for there is little doubt that this terrace is actually a double feature.

The eastern portions of the 100-ft. fragments have an average slope of $13\frac{1}{2}$ ft. per mile below 120 ft., and a markedly higher figure is obtained once spot-heights of 120 ft. and over are included. This suggests that the 100-ft. surface is composite, with a separate lower sub-stage occurring below 120 ft. No satisfactory transverse gradient for the possible upper sub-stage can be obtained. Though at one point it

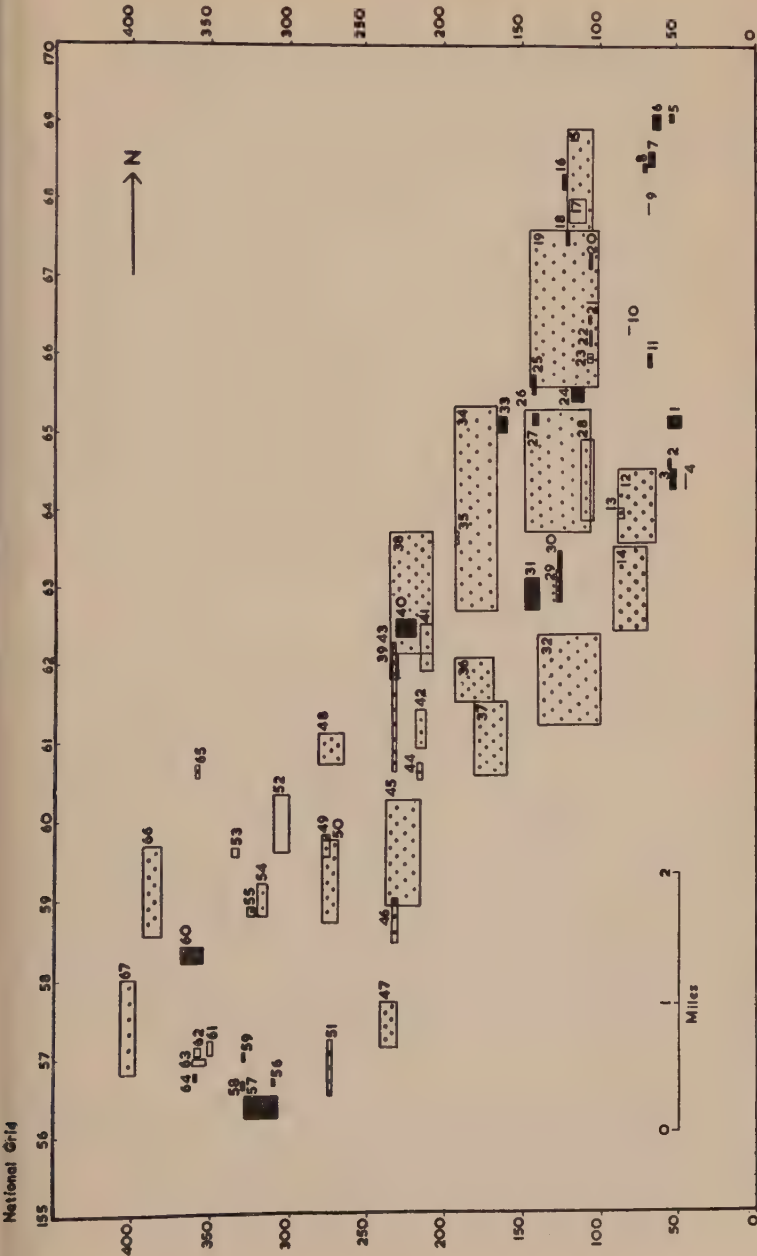


FIG. 3.—HEIGHT-RANGE DIAGRAM OF THE MAIN FLATS OF THE BLEAU. (See text, page 67). *Stippled*: Flats developed on gravel at least three feet in depth. *Black*: Gravel noted at the surface but no information on thickness. *White*: No gravel observations. Small flats on isolated hillocks possibly degraded considerably below their true level.

is as low as 10 ft. per mile, the figures are both too inconsistent and too few to yield a valid average. The slope separating the two sub-stages is clearly steeper as measured on the map, though indistinguishable from them on the ground. A little support for its existence is drawn from the terrace-fragments of a left-bank tributary which joined the Stour near Ford in the 100-ft. period. It is one of a number of tributaries which lengthened themselves eastward across the Blean in the wake of the migrating Stour. Today it is represented by a mere shrunken remnant, the North Stream, but its 100-ft. terrace can be traced westward for six miles, rising to 125 ft., and beyond that a little more steeply. This is considerably lower than the back of the 100-ft. terrace though it grades to the front of it. A few fragments, along approximately the same line, lie between 135 ft. and 150 ft. As this is 25–30 ft. higher than the first series, it must have graded into the Stour at 125–130 ft. This again strongly suggests the separate origin of the western part of the terrace. Even at higher levels the eastward migration of the Stour has left the terraces difficult to separate. Here, where the vertical interval between two successive phases was very small, that difficulty is still further accentuated. This fact is reminiscent of the difficulty of separating the 100-ft. and 130-ft. levels in the Dartford area, which after much disputation were demonstrated by Green as distinct.

(c) The evidence of the Little Stour

The most important of the Stour's tributaries is the Little Stour, and this affords further evidence of eastward migration at the 100-ft. stage. The 100–125-ft. terrace of the Little Stour is almost as extensive as that of the Stour itself, and a first reaction to this evidence taken alone is to regard the two aligned north–south courses as a unitary consequent stream from which a left-bank tributary has intercepted the Middle Stour flowing out of its chalk gap, and diverted it eastward (Fig. 1). But this line of argument is quite untenable: the stages already demonstrated show that the Stour had indisputably worked its own steady passage eastward, stage by stage, and that, patently, no evidence of such sudden capture-diversion exists. Nevertheless, the contrast between the sturdy breadth of the Little Stour's terrace and the tenuous threads of terrace evidence that bind the main 100-ft. surface to the Stour Gap, does pose a problem. It is to be noted that in the north–south terrace of both rivers, a broadening occurs which is absent from the ENE.-reach of the main stream.

(d) Surfaces below 100 ft.

The general remarks which apply to all the stages above 100 ft. do not, on the whole, apply to the lower terraces. In fact, a number of marked contrasts appear at this level (Fig. 1). These are:

- i. The main flats below 100 ft. are smaller.
- ii. They are backed by definite bluffs in most cases.

- iii. They are not so flat as the higher surfaces and represent a less perfect levelling of the area.
- iv. They cannot so readily be correlated in height among themselves. They are fragments of a composite and not a simple stage. For this reason it is convenient to assign to them the name of 'Reculver Stage', rather than a height designation.
- v. They occur both on the Blean and on the Thanet side of the flood-plain. Unless they pertain to two separate valleys, they represent an original width of three miles.

These observations allow the denudation chronology of the area to be continued as follows.

Subsequently to the 100-ft. stage, migration brought the Stour yet further east, so as to flow on the Chalk which no doubt checked further eastward movement. That it remained roughly stationary after this stage is indicated by the existence of the buried channel, now filled with the alluvium of the Wantsum Marshes, but originally incised in the Reculver Stage flood-plain, leaving relics of that flood-plain on both the Blean and the Thanet sides. This is a quite unique stage in the history of the Blean, since at all previous stages terrace remnants were preserved on the western side only.

The existence of river-bluffs against the 100-ft. terrace in the neighbourhood of Reculver, is evidence that stabilisation of the Stour's position was achieved during, and not merely after, the Reculver Stage. Eastward movement must have ceased to have allowed the river so strongly to undercut its western bank. During the Reculver Stage undercutting the river seems to have occupied many levels sufficiently long to have cut small flats, which at first sight might be taken as marking numerous independent sub-stages. But the two large flats of the South (Nos. 12 and 14) provide a basis for grouping. No. 14 falls eastward from 92 ft. to 70 ft.; 12 from 89 ft. to 64 ft. They clearly belong together. Their seaward fall varies between 3 ft. and 13 ft. per mile, and this makes it possible to assign to their sub-stage a terrace near Highfield with a back at 82 ft. It is not clear whether the group which reaches the sea at 53 ft. to 66 ft. near Reculver is part of the same or a slightly later sub-stage. A definitely lower surface is discernible at between 45 ft. and 55 ft. inland at Chislet. It does not reach the sea and must formerly have run out over the site of the present marshes.

At present the Reculver branch of the Stour Valley is occupied by a minor distributary, the Wantsum, while the main discharge reaches the sea on the southern side of the Isle of Thanet. The history of this final diversion is somewhat obscure, since it is bound up with the excavation of the buried channel which lies beneath an unknown depth of alluvium and cannot be adequately investigated. The only certain figure is the 66 ft. of drift recorded in the Ebbsfleet boring, and as this is not central to the alluvial tract it probably does not

represent the maximum thickness. In spite of this difficulty, it seems reasonable that the final stages in the development of the Stour were in outline as follows. The north-south lower reach may have been perpetuated from Reculver times into the succeeding buried channel period, when a valley would have been excavated under the site of Chislet Marshes. This deep valley must have extended for some miles upstream and possibly beyond Canterbury. At the same time another stream roughly followed the centre of the Wantsum Syncline. It probably flowed eastward to the forerunner of Pegwell Bay, though a westward direction as a tributary of the Stour is not precluded. This stream must similarly have deepened its valley below Ordnance Datum. At the onset of the Flandrian Transgression, both these valleys must have been converted into marine rias. Their waters coalesced at Stourmouth to form the through strait which separated the Isle of Thanet from the mainland of Kent. The valley of the Stour above Stourmouth was invaded by the sea to a point upstream of Canterbury, and there had been little progress in its silting-up when the Romans came. Later silting is as much a matter of history as of geology. As the mouth of the Stour advanced downstream, its waters were discharged both to the west and to the south of Thanet: the latter, or Richborough, branch has become the more important during the course of the centuries.

Since there is at present no evidence of the buried channel in the Reculver branch, although it was certainly excavated below the level of the Reculver Stage, other interpretations are possible. The Stour may, for instance, have taken up its present line before or during the buried channel phase, and have held it ever since. The former explanation has been treated in more detail, however, since it appears the simplest hypothesis which can be advanced on the slender basis of the known facts.

4. CAUSES OF THE EASTERLY MIGRATION OF THE STOUR

During the formation of its terrace sequence north of Canterbury the Stour migrated a distance of thirteen miles. This shifting was distributed evenly and regularly through all the stages until after the beginning of the Reculver period and then stopped. It is necessary to seek some secular, uniformly operating cause for this large-scale movement. A number of alternative explanations have been considered, but failed to meet the case. Their deficiencies may be briefly examined.

(a) The Earth's rotation

The well-known tendency of the earth's rotation, to deflect moving bodies to the right in the Northern Hemisphere, has occasionally been invoked to explain asymmetrical valleys (Martonne, E. de, 1926). Superficially the Stour's movement to the right appears an excellent illustration of the law, but, in fact, migration has been on

far too grand a scale to be referred, plausibly, to a force which has produced no appreciable effect in the other valleys of south-east England. This explanation is, therefore, improbable.

(b) Structural guidance

Persistent movement of a river in the same direction frequently denotes the directing influence of structure. It is therefore necessary to examine the structure of the Blean. Whitaker (1872) claimed that the Blean possessed an inward dip on all sides except the coast. He also noted that the pitching western end of the Thanet Anticline was traceable well into the Blean. Wooldridge (1926) amplified Whitaker's cautious statement with a map showing two infacing north-south monoclines bounding the east and west edges of the Blean. Collins and Gill (1923) demonstrated the existence of two small east-west anticlines in the western Blean. The one-inch geological map might suggest a through syncline whose axis continues the Wantsum Syncline (south of Thanet) diagonally across the Blean and into Sheppey where the Bagshot Beds are preserved along the same axial zone. This represents the Blean as being predominantly a NW.-SE.-trough of Lōndon Clay, with Lower London Tertiaries rising from beneath it to the north-east and south-west.

These various interpretations of structure are not altogether mutually compatible and, in order to throw further light upon them, a stratum contour map of the Eocene base in north-east Kent has been constructed (Fig. 4). This map is based upon the data recorded in the Geological Survey's Water Supply Pamphlets. Contours are in general at 50 ft. intervals, with a few additional ones where the information was abundant. The map indicates that—

- i. The eastern monocline, visible in the cliffs east of Herne Bay, rapidly dies out southward.
- ii. The pitching end of the Thanet anticline penetrates well into the Blean, at least as far as Herne, where an inlier of Woolwich Beds is exposed.
- iii. The Wantsum Syncline does continue diagonally across the Blean, but not so simply as might first appear. It is arcuate in plan, crossing the coast a little east of Swalecliffe. In Sheppey a normal northward dip is resumed.
- iv. The western and south-western part of the Blean is complicated by east-west folding. The northern anticline of Collins and Gill is clearly apparent. No flexure is discernible along the southern line they suggested, but there is a second anticline further south. These may be termed the Hernhill and Blean-Broad oak Anticlines respectively, and their complementary downfolds the Denstroude and Canterbury Synclines. These flexures pitch towards the centre of the Blean, and fade out east of Canterbury.
- v. The western monocline, if present, is effectively dwarfed by the other structures.

This analysis of structure makes it quite clear that the migration of the Stour has been quite independent of structural influences. At each stage in its passage across the Blean, it has flowed discordantly

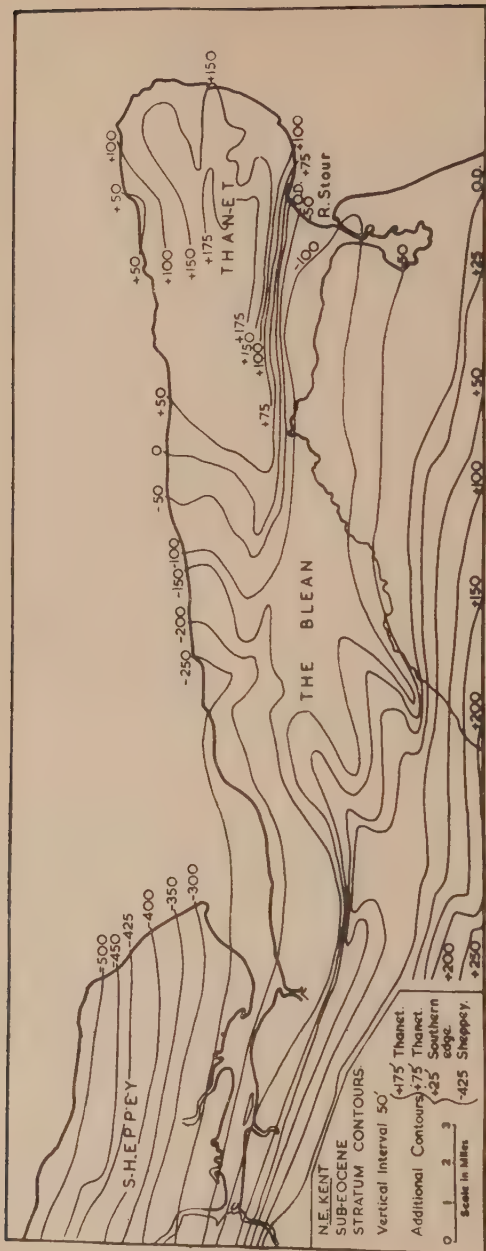


FIG. 4.—CONTOURS OF THE EOCENE BASE. Comparison with Fig. 1 shows the Stour's lack of adaptation to structure throughout its traverse of the Blean.

across the folds mentioned. Lack of adaptation to structure is not an unusual feature of streams developed on outcrops of homogeneous clay. What *is* remarkable is the strict parallelism that has been maintained in the absence of structural control.

(c) Tectonic deformation

There remains the possibility that the area has been subject to earth movement. A gentle secular tilting with an appreciable easterly component seems to be the only explanation competent to cover the facts. As a working hypothesis it may well explain the following observations:

- i. The fact that the terraces of both the Great and Little Stour are broad where they run from south to north, whereas the ENE. valley reach of the Great Stour is much narrower.
- ii. The persistence and regularity of the migration.
- iii. The fact that the transverse gradients of the terraces increase with age, since the older flats would have been subject to tilting over a longer period than the younger.

A hypothesis such as this, which disposes of the outstanding problems of the region, cannot readily be dismissed, though it must be regarded with caution. It must be considered in relation to a wider territory to ascertain whether it is acceptable regionally. It is proposed to argue that the margin of the geosynclinal tract of the North Sea Basin shows evidence of late and recurrent deformation of which the postulated movement of the Blean area may well be part.

The Blean surfaces are lower and more recent than the apparently unwarped Pliocene platform. If this absence of warping were to be taken as applying to the whole of south-east England there could evidently be no question of explaining the Stour terrace sequence as has been proposed. It is therefore necessary to inquire what limits can be assigned to the generally unwarped area. A reconstruction of the sub-Pliocene surface has been attempted by Wooldridge and Linton (1939); it cannot be placed lower than the level of the highest hill-tops of western Essex (*ca.* 500 ft.), but eastward it must decline towards the coast, for the Red Crag outlier at Walton lies at about 70 ft. We may recall that, at Amsterdam, it is found at a depth of —400 m. (—1312 ft.) O.D. (Harmer, F. W., 1896) and is covered with a great thickness of Pliocene followed by Quaternary beds. This proves the continuance of geosynclinal subsidence to a late date; in fact, it amply covers the time-range of warping in the Blean.

We may also recall the findings of Captain T. E. Longfield of the Ordnance Survey (1932). His published map showing the discrepancies of level between the first and second geodetic levellings of the country is distinctly suggestive. Apart from possible indications of a wider tilting movement, the map might quite plausibly be interpreted as showing a recrudescence of tilting on the North Sea margin in Kent and East Anglia.

Pending further work the possible limits of any downwarped tract will not be pursued further here. It may be pointed out, however, that the observations and suggestions made are not inconsistent with other evidence which might be adduced from the Medway Valley and from the northern flank of the Bolonnais. In the latter area, pronounced north-easterly inclination of the Pliocene beds is not in doubt. In the former case the revised Chatham sheet, recently issued by H.M. Geological Survey, is of great interest. The terraces of the Medway there mapped betoken a similar easterly migration of the lower river: a similar cause must at least be considered. These facts indicate a peripheral pattern of warping by no means inconsistent with the type of movement here invoked in the Blean.

5. BASES OF CORRELATION

If warping has indeed affected east Kent, correlation with stable areas in south-east England should reveal the amount of displacement, thus providing a confirmatory test of the hypothesis. But the establishment of correlation is always difficult and this is particularly true of the present attempt, which must be regarded as purely tentative.

If the hypothesis proposed is substantiated, correlation cannot rest on similarities of height, but five other bases suggest themselves:

- (a) Archaeological dating.
- (b) Character of the deposits.
- (c) Relative size of the reconstructed surfaces.
- (d) Longitudinal gradients of the surfaces.
- (e) Vertical spacing of the surfaces.

Though no one of these can be conclusive in itself, any combined testimony would be difficult to refute. Geomorphologists working in other areas have not always provided the data whereby all these tests can be applied.

It is proposed to examine the theoretical implications of each basis, and to describe its development in the Blean.

(a) Archaeological dating

It is necessary to identify the same stages in both correlative series. If this can be done for one terrace only it provides a starting point for correlation.

In the Stour Valley below Canterbury two gravel pits have yielded early human artefacts. Those recorded by Dewey (1925) at Sturry are of St. Acheul II and le Moustier date, with a few derived Chelles hand-axes. On this evidence Dewey considered that the terrace in which they occur is later than the 100-ft. terrace at Swanscombe. It is also later, on morphological grounds, than the 100-ft. terrace of the Blean. Smith, in 1933, described implements taken from the upper, or

125 ft., substage of the 100-ft. terrace of the Little Stour. They were of mixed Clacton and St. Acheul types, and he equated them with those of the 100-ft. terrace at Swanscombe. Clactonian and Acheulian tools have also been found in the 100-ft. terrace near Reculver.

This evidence is not as conclusive as would be desirable, but it does suggest that the 100-ft. terrace on the Blean is still at its original level, a product of the same erosion stage as the Boyn Hill terrace of the Thames at Swanscombe and Dartford. This accords well with the earlier conclusion that eastward migration, and therefore tilting, ceased after the end of the 100-ft. period.

(b) Character of the drift

No light is to be gained from the constitution of the gravels, since the same materials have been used over and over again. But the grade of material and pattern of stratification, which reflect physical conditions, may show a similarity in two adjacent areas. The Blean gravels may be divided into four groups on this basis:

(i) Normal riverine gravels occur below 150 ft. and vary in thickness between 4 ft. and 8 ft. Their constituents include: (a) numerous black Tertiary flint pebbles, a small proportion of which are jasperised to a rich red, and broken into small pieces; (b) angular and sub-angular flints from the Chalk. The orange and yellow specimens are more common, and rather smaller, while those which grade in colour from black through blue and grey to white, which are normally possessed of a white patina and attain a larger maximum size of about five inches; (c) ironstone derived from the Folkestone, Oldhaven and Lenham Beds. Fragments of septaria from the London Clay occurs in the 125-ft. and lower terraces.

The gravels are usually roughly bedded, with bands of sand or loam up to 1 ft. in thickness.

Sections are available in the 100-ft. terrace at Ford (204660),¹ Millbank (204653), Highstead (214661); in the 125-ft. terrace at Westbere (188614), in the Upper Reculver Terrace at Sturry (175606).

(ii) The second group is constituted identically with the first but is not stratified, and occurs only in small patches. The matrix is clayey. These patches characterise the surfaces between 350 ft. and 160 ft.

(iii) A third group of gravels occurs on the southern parts of the 205-ft. and 265-ft. surfaces. Numerous exposures at both levels occur west of Canterbury on the ridge which carries the Pilgrims' Way from Bigberry Camp to Chartham Hatch. These sections were described collectively by Wooldridge (1925). In his view their coarse grade, considerable thickness and tumultuous torrent-bedding pointed to a periglacial origin, and this also is the opinion of the present writer. Twenty-five miles is a generous estimate of the

¹ Six-figure national grid references are employed to show the position of sections. The best exposures are marked in *italics*.

maximum latitudinal distance from the ice-edge. Fifteen miles is a truer figure for the northern Blean. Consequently snow-melt and river-ice in large quantities should have affected the lithology of the periglacial terraces. A disused pit in the 205-ft. terrace (111573) presents a gravel-face about 16 ft. in height, interrupted by discontinuous bands of coarse, strongly iron-stained sands. Similar sands form a matrix for Tertiary flint pebbles, rolled Chalk flints—some nearly 1 ft. in length—ironstone and sarsen fragments. Hooker's Pit (105569) exposes 12 ft. of gravel in the 265-ft. terrace. The constituents are extremely coarse, including flint cobbles over a foot in length, and blocks of sarsen of up to 2 ft. Ironstones have been obtained from an adjacent pit. The gravel courses are irregularly scoured and interrupted by current-bedded bands and banks of a coarse stony sand, streaked with black manganiferous limonite. The matrix of the gravel itself is of a similar material. The gravels here overlie Woolwich Beds, and as the basal surface is exhumed there is gradually emerging an elongated 'scoop' which appears to be an old stream channel. Though this drift is not traceable northward, it does recur upstream at Old Wive's Lees where a surface at 283 ft. is thickly littered with blocks of flint and ironstone. Similar boulder-rich deposits are common at about this level throughout south-eastern England, and this suggests that any derangement caused by warping must have been only very slight.

(iv) The drift of the High Blean surface is variable. Considerable areas are covered with gravels similar to that of the first and second groups. Part of the western edge, above Rhode Common, carries no deposit, but is developed directly on London Clay. A trench at Dunkirk (074590) exposes at least three feet of an unusual gravel, consisting of rolled ochreous flints about nine inches long, with a thick white patina. Tertiary flint pebbles are associated. The matrix is clayey and iron-stained. This drift certainly has no resemblance to the Pebble Gravel found at similar heights elsewhere in the London Basin.

(c) Size of reconstructed surfaces

The breadth of a terrace or river-cut flat is a function of several variables, of which the chief is the duration of lateral cutting, i.e., of 'stillstand'. In so far as stillstand reflects a pause in tectonic or eustatic movement, its effects will be felt by a number of neighbouring rivers, and perhaps throughout a wide region. This possible basis of correlation is frequently rendered invalid when later erosion reduces large terraces beyond the possibility of faithful reconstruction, but any such serious reduction can readily be detected by noting the varying heights of the bounding lower bluffs. It has already been noted that the original breadths of the old flood-plains above 100 ft. of the Stour have probably been preserved almost intact, but another more

specialised factor may have complicated this relationship. This factor is the warping itself. Any minor fluctuations in its rate may well have differentially hastened or delayed the migration of the Stour. It may, therefore, have been more influential than the time factor in determining terrace breadths. The breadths in question are:

High Blean Stage	...	...	...	...	1000	yards
350 ft.	"	...	...	...	700	"
300 ft.	"	...	...	...	1800	"
265 ft.	"	...	...	...	1700	"
205 ft.	"	...	...	...	3600	"
160 ft.	"	...	...	...	2800	"
125 ft.	"	...	...	...	1900	"
100 ft.	"	...	...	...	1600	"
Upper Reculver Stage	...	...	...	...	1800	"

(A minimum figure, since frontal bluffs occur everywhere.)

Lower Reculver Stage	...	...	...	...	500	"
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(Clearly reduced by later erosion.)

This possible method, based on terrace width, has been outlined because, although it is probably inapplicable here, it will avail more generally over a wider region, and has not, so far as is known, been employed quantitatively hitherto.

(d) Gradient

The longitudinal gradients must also be treated in a relative sense. If in any locality one terrace shows a markedly stronger rate of fall than that above or below it, it is likely that it would correspond with a similarly steeper terrace in a neighbouring river basin.

Most of the Stour terraces have no marked longitudinal gradient, but the Reculver Stages, the 205-ft. Stage and the High Blean surface show a definite northward fall. The explanation is believed to be different for each. For the first, it appears to spring from a general incompleteness of levelling during a normal fluvial phase. For the second, the mouth of the river is believed to have lain some distance north, and a glacial association is suggested by the coarse nature of the drift-deposits. For the third, a tectonic cause may be invoked as at least a partial explanation. The gradient may well reflect a marked early, but non-recurrent, northerly component in the tilting. In general, however, High Blean surface with its varied drift-types remains rather enigmatical.

(e) Vertical spacing of the terraces

This is an important though delicate method of correlation. It is an attempt to combine the normal method of height comparison with an allowance for tectonic derangement. It consists essentially of comparing the intervals between the terraces in two areas and noting

any general correspondence of features even when there is no absolute height-agreement. The task is, of course, simplified where archaeological evidence provides a starting point. The vertical spacing graphs (Fig. 5) show spacing plotted against stage, thus producing a 'curve' for each area. For perfect correlation, curves for two areas should be coincident. However, in an area where downward tilting has been demonstrated, the correspondence cannot be exact, and it is necessary to determine what constitutes a significant disparity. If all the surfaces are lower than corresponding ones in the correlative series, this

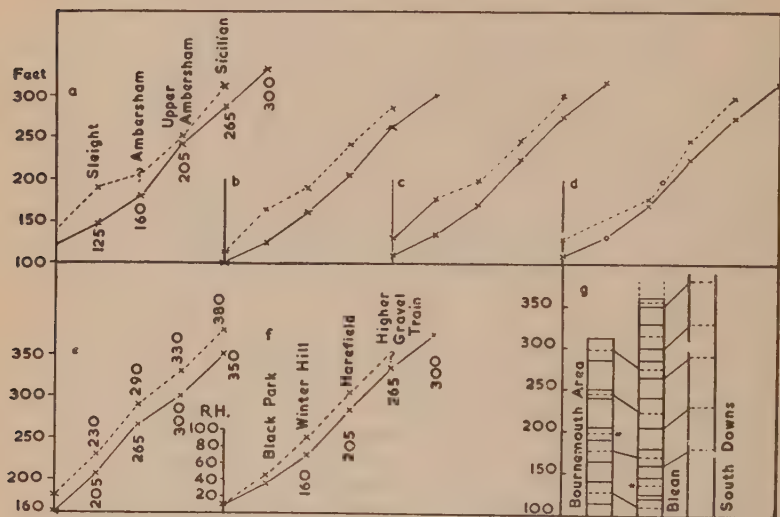


FIG. 5.—VERTICAL SPACING GRAPHS. (a-d) Comparison of the Blean and Bournemouth surfaces (Green). (a) Back Heights of Terraces; (b) Forward Heights; (c) Median Heights; (d) Assuming that the 125-ft. stage is missing from Bournemouth and the Ambersham stage from the Blean; (e) Correlation with old South Down sea levels (Sparks); (f) Correlation with Middle Thames terraces (Hare); (g) Alternative diagrammatic expression of d and e.

would be significant. If the older surfaces, subject to tilting over a longer period than the younger ones, show a progressive divergence from the normal curve, this would be even more significant. But if positive and negative disparities alternate in irregular fashion, with the two lines crossing and recrossing each other, then no significance can be read into the graph and no correlation can be made. The problem must then be solved by field work in the region lying between the two correlative areas.

SUMMARY OF VERTICAL SPACING

High Blean Stage: The interval increases southward from 0-48 ft. (back).
350-ft. Stage:

50 ft. (front), 30 ft. (back).

300-ft. Stage: 35 ft. (front), 45 ft. (back).

265-ft. Stage: 60 ft. (front), 45 ft. (back).

205-ft. Stage: 45 ft. (front), 60 ft. (back).

160-ft. Stage: 35 ft. (front), 35 ft. (back).

125-ft. Stage: 25 ft. (front), 25 ft. (back).

100-ft. Stage: 30 ft. (front), 30 ft. (back).

Upper Reculver Stage:
20 ft. or less.

Lower Reculver Stage:
Between 30 ft. and 50 ft.

Flood-plain: The small and regular size of the intervals between the Blean terraces is a disadvantage in correlation. It is less easy to confuse stages which are separated by large irregular and, therefore, highly individual intervals.

It is now proposed to apply these various bases of correlation to actual comparisons of the Blean surfaces with those of specific areas in south-east England.

6. ATTEMPTED CORRELATION WITH SPECIFIC AREAS

(a) The Bournemouth area

The natural place to seek a correlation with the Blean terraces is in the more westerly parts of the London Basin where widespread morphological observations have been made. The more scattered evidence is not altogether satisfactory for a detailed comparison: what is required is a complete sequence in a relatively restricted area, based on careful morphological mapping. Though such a sequence, mapped by Professor F. K. Hare, does exist in the middle Thames Basin, it is unsuitable for correlation with the Blean for several reasons. The two obvious difficulties are the warping postulated in the Blean, and the sixty miles of inland ascent of the Thames. In addition the Thames is within the area of maximum glaciation, which introduces the possibility of 'crossed terraces' such as those of the Rhine. Furthermore, the major changes of course, believed to have occurred in the Middle Thames, adds another complication to the relative spacing of terraces there.

For these reasons no weight can be placed upon the surprisingly close correspondence of vertical spacing between the Blean and

Middle Thames surfaces, and it is necessary to look outside the London Basin for other suitable platform or terrace sequences. The Bournemouth area and the South Downs, mapped by Green (1946) and Sparks (1949) respectively, have been selected for this purpose.

Correlation is attempted first with the terrace-flight mapped by J. F. N. Green in the Bournemouth area, not only because he was the initiator of detailed morphological survey, but also because these terraces, developed on Tertiary Beds near the coast, consequently are in conditions very similar to those of the Blean.

The archaeological evidence is not conclusive, and vertical spacing is the most promising approach. Numerous trial graphs have been drawn, and the most satisfactory ones prove to be those where the 100-ft. terrace is equated with the Boyn Hill terrace. Several variants of this correlation are shown in Fig. 5, where the median figures for each series are seen to give a rather closer parallelism than the figures for the back or front edges of the terraces. The correspondence remains far from perfect, however, although it is significant that the Blean levels are in all cases below their Bournemouth counterparts.

(b) The South Downs

The flight of marine platforms mapped in the South Downs by Sparks (1949) affords an adequate basis for correlations, since the levels given are claimed to be actual old sea levels, and those of the Blean are the lowest elevations of extensive flood-plains formed very near sea level. Thus, it is the forward heights that are valid for comparison. The vertical range of the two sets of flats is almost co-extensive, but the significant Boyn Hill level is not included in Sparks' results. However, as he aimed to fill the gap between the Boyn Hill (Goodwood) and the Pliocene Platform stages, which were already established in the South Downs, his lowest surface at 180 ft. may be taken as the one immediately above the composite Boyn Hill stage, and as equivalent to the 160-ft. level in the Blean. If these two stages are correlated a regular pattern emerges for the rest (see Fig. 5), but if Sparks' 180-ft. stage is fitted to any other Blean terrace, only a very unsatisfactory graph can be obtained. This fact justifies a certain confidence in the correlation:

<i>The Blean</i>	<i>South Downs</i>	<i>Amount of subsidence</i>
160 ft.	180 ft.	20 ft.
205 ft.	230 ft.	25 ft.
265 ft.	290 ft.	25 ft.
300 ft.	330 ft.	30 ft.
—	(345 ft.; minor stage)	—
350 ft.	380 ft.	30 ft.

The table and diagram (Fig. 5) show that if the surfaces paired together are really co-eval, then all the Blean surfaces are lower than

corresponding ones in the South Downs. This disparity gradually increases with age, a result wholly compatible with the tectonic hypothesis.

Sparks' marine surfaces are drift-free, and it is not possible to use the archaeological, lithological, or gradient criteria as checks; nor is the relative size of the surfaces in any way conclusive. Thus the correlation hangs upon vertical spacing alone. Nevertheless it must be allowed that it is highly suggestive and completely consistent with the evidence of warping. It is, therefore, provisionally adopted here.

A word of explanation should be added to defend the use of height-designation for all except the High Blean and Reculver Stages. It may be argued that the bodily tilting of the Blean terraces has thrown their elevations out of step with those of normal areas, and that they have therefore become not a means of correlation at sight, but a burdensome catalogue of numbers, barren of value for dating any save local periods of development. Nevertheless it has been decided to retain them as an interim measure partly on the grounds that a whole series of new names is equally burdensome, but chiefly because this area is a part of the London Basin, and it would be advantageous to wait until one can apply with certainty the names already established for the terraces of the Thames.

7. SUMMARY OF CONCLUSIONS

The work recorded in this paper appears to lead to the following conclusions.

The Blean is characterised by extensive flat surfaces which fall into eleven distinct groupings on the basis of height. They range, at roughly 50-ft. intervals, from 400 ft. to the modern alluvial flood-plain very near to sea level.

Each group of flats above the flood-plain is believed to represent an old valley-floor of the Great Stour, formed during successive erosional epicycles initiated by falls of sea level. Riverine deposits, as continuous or residual gravels, or possibly as stony alluvium, are associated with each stage.

The surfaces are ranged in an eastward descending sequence which denotes a sustained migration of the Stour. The migration has been proved, by examination of sub-Eocene stratum-contours, to be independent of structural guidance, and is believed to be the result of a slight secular warping of East Kent towards the North Sea geosyncline. The lines of evidence which support this interpretation are various. They have a high degree of mutual consistency.

In the first place the broad flat nature of the surfaces and the extremely gentle slope of the bluffs separating them, indicate the dominance of eastward movement over simple vertical incision. Secondly, the differential broadening of the Great and Little Stour terraces, according to whether they trend with or across the presumed

direction of tilting, is a valid point of favourable evidence. Again, the hypothesis is surely supported by the increase with age of the transverse gradient of the terraces. Further, a similar eastward migration on the part of the lower Medway suggests that the warping extended further west, while clear evidence of tilting from other parts of the North Sea Basin affords general support for the hypothesis. Finally, a comparison of the Blean surfaces with those of the South Downs reveal height discrepancies which again suggest that the Blean has been relatively depressed.

The dominant component in the warping is believed to have been easterly. A strong northerly component is recognisable at the highest stage only.

The inferred tilting is so slight as to lack serious distorting influence upon the surfaces. In fact, contrary to general expectation, the movement itself has been responsible for a better formation and preservation of the surfaces than would otherwise have occurred. Warping assisted the Stour to move more rapidly eastward, and so to plane larger areas than would have been possible in a stable area. Again, had the Stour remained in a roughly constant position, it would have destroyed large areas of its own terraces. But warping drew the river away from these surfaces and so preserved their original breadths. It is thus clear that the slight deformation experienced in the Blean was well below the critical amount at which it would cease to assist and would, instead, actively obliterate the morphological record.

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DISCUSSION

MR. A. P. HUMPHREYS congratulated Miss Coleman on her extremely interesting and lucidly presented paper. Having spent some of his earlier youth in the area, he had more than a passing interest in it.

The eastward tilt of the Blean and Medway areas may be traced to a lesser extent in the Isle of Sheppey. Here, streams tend to flow SSW. and S., but, on nearing their mouths, there is a marked tendency for them to swing towards the SE. Small 'terraces' exist to the west of some streams—these are not measurable with the aneroid.

Unfortunately not much is known of the tidal effects operating in this low-lying part of Sheppey, although of the two tides, one from the Medway and the other from the East Swale, the former appears to be increasing in strength, and their meeting point is thus gradually moving eastwards.

These very recent movements suggest an alteration resulting either from tilting or slight subsidence due to mud and marsh shrinkage; or, probably, from a combination of both. Since, however, a recrudescence of tilting is thought to have taken place in the past few thousand years in the Blean and Medway, it is plausible to assume that this has had an appreciable effect on the intermediate Sheppey area.

MR. G. E. HUTCHINGS congratulated the author on her careful and commendably imaginative piece of research. He was pleased that she had instituted a comparison between the Blean mass and the Hundred-of-Hoo peninsula. He felt sure that an examination of the newly-mapped superficial deposits over the Hundred-of-Hoo area would reveal a sequence of stages comparable with those on the Blean and, perhaps, closely accordant with them. An eastward down-stepping was readily apparent. Evidence had recently become available to show that the northward course of the Medway at the 'buried channel' stage lay between Allhallows and the Isle of Grain. It is marked in present-day topography by the broad belt of alluvial marshland traversed by Yantlet and Colemouth Creeks.

He ventured to make a correction to Miss Coleman's reconstruction of the Stour estuary in Roman times, suggesting that here, as elsewhere, the estuary was not a continuous sheet of open water with its coastline coinciding with the present-day landward edge of the marshland. He considered that the deposition of alluvium had kept pace with the intermittent subsidence and that at all stages the estuary presented a surface of marshland standing at the level of the highest tides and dissected by tidal waterways. That the estuary was not in Roman times a broad sheet of water is made evident by the exhumation of Roman land-surfaces well out towards the centre of the present alluvial tracts.

DR. J. F. KIRKALDY congratulated Miss Coleman on her very thorough study of the Blean. When Professor Wooldridge and the speaker, some years ago, had done a certain amount of work on the Blean, they had found that the morphological evidence for the eastward shift of the Stour, however caused, was unquestionable, but that exposures in the gravels, with so much of the ground heavily wooded, were regrettably few. He was particularly interested in the gravels of the Chartham Hatch ridge, which appeared to differ somewhat from those of the Blean proper, the Chartham Hatch gravels being thicker, coarser, and more tumultously bedded. Dr. Kirkaldy inquired Miss Coleman's views as to the mode of origin and northward extension of the gravels well exposed at Chartham Hatch.

THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1951

THE numerical strength of the Association on 31 December 1951, was as follows:

Honorary Members		20
Ordinary Members:		
Life Members (compounded)		187
Annual Subscribers		1835
		2042

During the year 209 new members were elected, and the Association lost 110 members through death, resignation and removals under Rule XI for failure to pay subscriptions. The membership continues to rise, and shows an increase of 102 over that of the previous year.

The list of deceased members is as follows: Miss Dorothea M. A. Bate, A. Burnet, L. A. Cammiade, R. T. Cornish, F. Crombie, M. B. Hodge, C. Johns, D. Kerr, G. W. Lepper, Rev. E. T. A. Lumby, W. C. Simmons, Miss M. H. Smith, and A. E. Thomas.

[Obituary notices will be found on pages 106-12.]

FINANCE

On the Income side of the General Purposes Account admission fees and annual subscriptions show revenue of £998 10s. as compared with £936 10s. in 1950, £850 10s. in 1949, and £826 in 1948. On the expenditure side of the Account, the cost of four Parts of the PROCEEDINGS (278 pages) appears as £1096 7s. 11d., as compared with £854 11s. 5d., the cost of the same number of parts in 1950 (306 pages). The cost of printing *Monthly Circulars* is £178 1s. 3d. as compared with £177 8s. 2d. in 1950. To meet the cost of these publications, it has been necessary to transfer the sum of £450 from the Special Funds to the General Purposes Account. After providing for the transfer, the balances in the various Special Funds, apart from the Reserve Fund for Index and List of Members, amount to £652 1s. 7d. This sum is available for the general purposes of the Association, and is in addition to the accumulated fund of £124 19s. 6d.

Although it has been necessary to transfer £350 from the Compounding Fund to the General Purposes Account, it is emphasised that the amount remaining in the Compounding Fund, more than covers the Association's actuarial liability in respect of Compounding Members.

The Association is grateful to the Council of the Royal Society for the allocation of £100, for 1950, from the Parliamentary Grant in aid

of Scientific Publications and for a further allocation of £150, for 1951, received since the closing of the accounts for the year.

It was with regret that, during the year, the Council was forced to ask the Members to agree to an increase in the Annual Subscription, the first since the Association was founded nearly 100 years ago. This action was necessitated by the large increase in the cost of printing and higher postage rates.

A Resolution to increase the annual subscription to one pound was passed at a Special General Meeting held on 5 October 1951, as announced in Circular No. 536.

It is hoped that the increased revenue from subscriptions in the coming year will remove the anxiety for the future financial position of the Association mentioned in the Annual Report for 1950.

Illustrations Fund

Contributions to this fund amounted to £86 2s. 6d. from 137 members as compared with £85 7s. 6d. from 146 members in 1950 and £61 3s. 8d. from 199 members in 1949.

TRUST FUNDS

Foulerton Award Fund

An award of £10 has been made from this Fund and the balance remaining in the Fund at the end of the year was £22 17s.

G. W. Young Geological Investigation Fund

No grant has been made from the Fund and the balance in hand at the close of the year was £72 10s. 9d.

Henry Stopes Memorial Fund

There has been no payment from the Fund. The balance at the end of the year was £19 17s. 2d.

PUBLICATIONS

Publications Committee.—The Committee consisted of the officers (seven) together with Dr. S. Buchan, Mr. A. J. Butler, Dr. G. W. Himus, Mr. G. S. Sweeting, Dr. H. Dighton Thomas and Mr. A. Wrigley.

The Committee met on five occasions and considered twenty-three papers, upon which reports were made to the Council.

Proceedings.—It has been possible to issue all four parts of Volume 62 during the year. The number of pages was 278.

MEETINGS

Nine ordinary meetings were held at which eight papers were read, five papers were 'taken as read' and one lecture was given.

The thanks of the Association are due to the authors and lecturers. In addition, two Special General Meetings were held for the purpose of amending the Rules.

Thanks are due to the Geological Society for the use of its apartments throughout the year.

REUNION

The Annual Reunion was held at the Chelsea Polytechnic on Saturday, 2 November. Many interesting exhibits were shown and the attendance was again high. Thanks are due to the Principal and staff of the Polytechnic and the members concerned.

FIELD MEETINGS

The Committee consisted of the officers (seven) together with Mr. E. E. S. Brown, Drs. G. W. Himus, W. S. Pitcher and M. K. Wells.

During the year there were six demonstrations, two half-day, seven whole-day, and two weekend field meetings as well as the usual Easter, Whitsun and Summer Field Meetings. In addition, a Summer Field Meeting was held in the Central Massif of France. One meeting was cancelled owing to lack of support. The thanks of the Association are due to the Directors and others, who organised and assisted at meetings.

The Council regrets that the attendance at several meetings was disappointingly small.

THE LIBRARY

The Library Committee consisted of the officers, together with Dr. S. Buchan, Messrs. R. V. Melville, G. S. Sweeting and J. Wilks, librarian of University College. Thanks are due to the donors of a number of books and pamphlets, listed in the PROCEEDINGS [p. 105]. The following overseas institutions have been added to the exchange list:

Service de la Carte Géologique de l'Algérie.

University of Bergen, Norway.

NORTH-EAST LANCASHIRE GROUP

Chairman: J. Ranson, A.M.I.M.E., F.G.S.

Secretary: D. H. Learoyd, B.Sc., F.G.S.

Committee: Mrs. E. J. Harrop, B.A., B.Sc., J. E. Carter, M.A., N. Thompson, S. Westhead.

During the year six lectures were given and four field meetings were held. Particulars will be published in the Report of the Session.

Thanks are due to the authorities of the People's College, Blackburn, for the use of rooms.

MIDLAND GROUP

Chairman: Professor F. W. Shotton, M.B.E., M.A., Sc.D., F.G.S.

Secretary and Treasurer: Miss Grace M. Bauer.

Committee: A. Bray, M.Sc., G. T. Warwick, M.B.E., B.Sc., F.R.G.S., E. D. Lacy, B.Sc., F.G.S., Miss B. M. E. Dudley, W. Waldron.

During the year five meetings were held at the Geological Department, The University, Birmingham, and there were four field meetings. Particulars will be published in the Report of the Session.

Thanks are due to Professor Shotton for the use of the Geology Department at the University for meetings.

NORTH STAFFORDSHIRE GROUP

Chairman: F. Wolverson Cope, D.Sc., M.I.Min.E., F.G.S.

Vice-Chairman: J. Myers, B.Sc., F.R.G.S., F.G.S.

Secretary: T. S. Purcell, B.Sc.

Treasurer: Miss M. W. O'Malley.

Field Meetings Secretary: J. T. Gleaves, B.A.

Committee: W. J. Adams, T. T. Hinchin, B.A., P. S. Keeling, B.Sc., A.R.S.M., F.G.S., J. C. Parrack, B.Sc., D. O. Thomas.

During the year eight meetings were held at the Arts Centre, Newcastle-under-Lyme, there were three field meetings and a Festival Exhibition. Particulars will be found in the Report of the Session.

Thanks are due to the authorities of the Arts Centre for the use of rooms.

TRUSTEES

The Trustees of the Association are:

Managing: Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S., and Mr. E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S.

Custodian: The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Mr. George S. Sweeting, D.I.C., F.G.S., for work of merit connected with the Association.

HOUSE LIST

Mr. T. Eastwood retires as President after two years' zealous application to the affairs of the Association, following seven years continuous service to the Association as Vice-President and Ordinary Member of Council.

Mr. A. Wrigley retires as Senior Vice-President and Miss Tomlinson and Mr. C. W. Wright as Ordinary Members of Council. Mr. W. Pickworth has resigned from the Council on his removal from London.

Thanks are due to these members for services rendered to the Association.

ACCOUNTS FOR THE YEAR ENDING 31 DECEMBER 1951

GENERAL PURPOSES ACCOUNT

INCOME		£ s. d.		EXPENDITURE		£ s. d.	
To Admission Fees :—				By 'Proceedings' of the Association (Vol. 61, Part 4, and Vol. 62, Parts 1, 2 and 3) :—			
Received for 1951 Elections	...	79	10 0	(1) Printing	...	879	16 5
Received for Arrears	...	15	10 0	(2) Illustrations	...	165	18 9
				(3) Authors' separate copies	...	50	12 9
Less Arrears at 31 December 1950, £20 10, estimated to realise	...	95	0 0	Printing Monthly Circulars	...	1096	7 11
		12	0 0	" Stationery	...	178	1 3
Add Arrears at 31 December 1951, £25 10, estimated to realise	...	83	0 0	" Expenses at Meetings	...	100	17 10
		15	0 0	" Expenses at Field Meetings	...	39	19 2
To Annual Subscriptions :—				" Addressing and Stock-keeping	...	16	15 5
(1) Received in 1944, 1948 and 1949 for 1951	...	3	10 0	" Postages	...	23	19 0
(2) Received in 1950 for 1951	...	86	10 0	" Insurance	...	182	2 9
(3) Received in 1951 for 1951	...	715	0 0	" Incidental Expenses	...	1	16 0
(4) Received in 1951 for arrears	...	75	10 0	" Yearly transfer to Reserve Fund for Index and List of Members	...	13	14 1
		880	10 0			40	0 0
Less Arrears at 31 December 1950, £121, estimated to realise	...	80	0 0				
		800	10 0				
Add Arrears at 31 December 1951, £138, estimated to realise	...	100	0 0				
To Royal Society Grant, 1950	...	900	10 0				
" Sale of Publications	...	100	0 0				
" Miscellaneous receipts	...	115	17 4				
" Transfer from other Accounts :—		7	17 6				
From Illustrations Fund	...	100	0 0				
" Compounding Fund	...	350	0 0				
		450	0 0				
Excess of Expenditure over Income for the year	...	21	8 7				

£1693 13 5

£1693 13 5

BALANCE SHEET, 31 DECEMBER 1951

LIABILITIES

	£	s.	d.	£	s.	d.
To Annual Subscriptions received in advance :—						
In 1948 for 1952/54	1	10	0			
In 1949 for 1952/54	2	0	0			
In 1950 for 1952/54	5	10	0			
In 1951 for 1952	89	10	0			
In 1951 for 1953	2	10	0			
				101	0	0
Sundry Creditors :—						
Messrs. Benham & Co. Ltd.				292	7	9
Special Funds :—						
Illustrations Fund	57	6	1			
Illustrations Fund (Capital)	20	0	0			
Reserve Fund for Index and List of Members	230	2	3			
Compounding Fund	1735	2	5			
Bequest Funds	784	19	8			
General Reserve Fund	329	0	0			
				3156	10	5
Accumulated Funds at 1 January 1951	146	8	1	3549	18	2
Deduct Excess of Expenditure over Income for the year	21	8	7			
				124	19	6

£3674 17 8

ASSETS

	£	s.	d.	£	s.	d.
By Investments (Special Funds) at cost or value when acquired :—						
Bequest Funds—						
£143 8 9 3¼% War Stock	141	14	0			
£150 New Zealand 3½% Stock, 1960/64	122	5	0			
£285 3% Defence Bonds	285	0	0			
£100 3% Savings Bonds, 1960/70	100	0	0			
				648	19	0
Compounding Fund—						
£1217 2 6 Nottingham Corporation 3% Irredeemable Stock	1152	13	2			
£200 3% Savings Bonds, 1955/65	200	0	0			
£170 3½% War Stock	152	14	5			
£100 3% Savings Bonds, 1965/75	100	0	0			
				1605	7	7
Illustrations Fund (Capital)—						
£21 0 10 Metropolitan Water Board 3% B Stock	20	0	0			
Annual Subscriptions in Arrears, £138, estimated to realise	100	0	0			
Admission Fees in Arrears, £25 10s., estimated to realise	15	0	0			
Cash at Bankers and in Office :—						
At Bankers	392	18	11			
In Office	10	8	4			
				403	7	3
Special Funds :—						
Illustrations Fund at Bankers	57	6	1			
Compounding Fund at Bankers	129	14	10			
Reserve Fund for Index and List of Members at Bankers	230	2	3			
General Reserve Fund at Bankers	329	0	0			
Bequest Funds at Bankers	34	15	8			
" " in Post Office Savings Bank	101	5	0			
				882	3	10
				£3674	17	8

SPECIAL ACCOUNTS

ILLUSTRATIONS FUND

	£	s.	d.	£	s.	d.
To Balance in hand on 1 January 1951	70	11	1			
Donations and Subscriptions	86	2	6			
Transfer from Illustrations Fund (Capital)	12		6			
				157	6	1

By Transfer to General Purposes Account for Illustrations
" Balance 31 December 1951, at Bankers

£157 6 1

SPECIAL ACCOUNTS (continued)

ILLUSTRATIONS FUND (CAPITAL)

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1951 ...	...	...	0 0 0	By Transfer to Illustrations Fund	...	...	12 6
" Dividends as received :—	...	...	...	" Balance 31 December 1951 ...	...	...	0 0 0
£21 0 10 Metropolitan Water Board 3% B Stock	...	...	12 6				
							<u>£0 12 6</u>

COMPOUNDING FUND

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1951 ...	...	...	266 6 4	By Transfer to General Purposes Account	...	...	350 0 0
" Composition Fees received during the year ...	...	...	161 19 0	" Balance 31 December 1951, at Bankers	...	...	129 14 10
" Dividends as received :—							
£1,217 2 6 Nottingham Corporation 3% Stock	36	10	2				
£170 3¼% War Stock ...	5	19	0				
£300 3% Savings Bonds...	9	0	0				
			<u>51 9 2</u>				
							<u>£479 14 10</u>

RESERVE FUND FOR INDEX AND LIST OF MEMBERS

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1951 ...	...	...	190 2 3	By Balance 31 December 1951, at Bankers	...	...	230 2 3
" Yearly Reservation for 1951 ...	...	...	40 0 0				
			<u>£230 2 3</u>				<u>£230 2 3</u>

BEQUEST FUNDS

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1951 ...	...	...	112 19 2	By Balance 31 December 1951, at Bankers	...	...	34 15 8
" Dividends as received :—				" " " in Post Office Savings Bank ...	...	...	101 5 0
£143 8 9 3¼% War Stock	5	0	6				
£150 New Zealand 3½% Stock ...	5	5	0				
£285 3% Defence Bonds	8	11	0				
£100 3% Savings Bonds, 1960/70	3	0	0				
			<u>21 16 6</u>				
" Interest on Post Office Savings Bank Deposit	...	...	1 5 0				
							<u>£136 0 8</u>

GENERAL RESERVE FUND

	£	s.	d.
To Balance in hand on 1 January 1951 ...	...	...	£329 0 0
			<u>£329 0 0</u>

‘TRUST’ FUNDS

FOULERTON AWARD FUND

To Balance in hand on 1 January 1951	...	...	£	s.	d.
" Dividends as received :—	...	...	...	22	9 10
£349 7 British Transport 3% Guaranteed Stock	...	...	...	5	12 9
" Income Tax repayment for 1950/51	...	...	...	4	14 5
			£32	17	0
			£32	17	0

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

To Balance in hand on 1 January 1951	...	...	£	s.	d.
" Income Tax repayment for 1950/51	...	...	...	70	2 5
	...	...	...	6	4 2
			£76	6	7

HENRY STOPES MEMORIAL FUND

To Balance in hand on 1 January 1951	...	...	...	£	s.	d.
" Dividends as received :—				...	11	19 8
£265 19 2 Government of Newfoundland 3% Stock, 1943/63				4	5	10
" Income Tax repayment for 1950/51	...	...	...	3	11	8
				£19	17	2

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65 £100 3% Savings Bonds, 1965/75, and £170 3½% War Stock of the Compounding Fund; £349 7 0 British Transport 3% Guaranteed Stock, 1978/88, of the Foulerton Award Fund; £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock, 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds, 1960/70, of the Bequest Funds; £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital); and £265 19 2 Government of Newfoundland 3% Stock, 1943/63, of the Henry Stopes Memorial Fund.

R. W. POCKOCK, D.Sc., F.G.S., Treasurer.

26 January 1952.

A. F. HALLIMOND }
R. BRADSHAW } *Auditors.*

REPORT OF THE SESSION 1951

Ordinary Meeting, 5 January 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Arthur Charles Allen, B.Sc., William Cameron Anderson, F.G.S., Miss Joyce Mary Andrews, John Edwin Barker, James Birch, Keith Bloomfield, Martin Arthur Brunt, Kenneth William Wilberforce Double, Charles Henry Emeleus, Geoffrey Philip Francis Ferrell, Colin Vincent Fleetwood, Alan Robert James Gaskin, John William Green, Brian Hitchon, Lionel Edgar Iredale, John Lawrence Knill, Michael John Lofting, Alfred Tennyson Parsons, George William Verdun Stark, Frederick John Venn, Sidney Waller and B. D. R. Worthington were elected Members of the Association.

Mr. W. S. Pitcher and Dr. A. F. Hallimond were elected Auditors of the accounts for 1950.

The following lecture was delivered: 'The Geological Survey's Contribution to Ground-Water Research', by Stevenson Buchan, Ph.D., B.Sc.

Ordinary Meeting, 2 February 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Walter Bishop, Stanley Reeves Broderick, M.I.C.E., F.G.S., Randall Davis, Norman Edgar Fourmy, Donald Peter French, Edward Alan Jobbins, B.Sc., Robert Macdonald, Abbas Marjani, Peter Mitchell, Miss Dora Morris, Don Bandusiri Pattiaratchi, David Anthony Pickard, Alan Phillips, Christopher Henry Thomas, Donald Victor Watkins and Geoffrey Wilson were elected Members of the Association.

The following papers were read: (1) The End-Moraine north of Flamborough Head, by A. Farrington, D.Sc. and G. F. Mitchell, M.A.; (2) The Erratics of the English Chalk, by Prof. L. Hawkes, D.Sc.

Annual General Meeting, 2 March 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

The Annual Report of the Council was taken as read. It was moved by Mr. W. S. Pitcher, seconded by Mr. R. Cheeseman, 'That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1949'. The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of Council in accordance with Rule XIII: President, T. Eastwood, A.R.C.S., M.I.M.M., F.G.S.; Vice-Presidents, A. Wrigley, G. W. Himus, Ph.D., F.G.S., A. G. Bell, I.S.O., B.Sc., F.G.S., E. Ernest S. Brown, M.B.E., F.G.S., D. Williams, M.Sc., Ph.D., B.E., F.G.S.; Treasurer, R. W. Pocock, D.Sc., F.G.S.; Secretaries, General—R. Reeley, F.G.S.; Field Meetings—T. Barnard, Ph.D., D.I.C., F.G.S.; Publications Committee—H. A. Hay-

ward, O.B.E., F.G.S.; Editor, C. D. Ovey, B.Sc., F.G.S., F.R.Met.S.; Librarian, L. R. Cox, M.A., Sc.D., F.R.S., F.G.S.; twelve other Members of the Council, B. Ainsley, F.G.S., Miss M. A. Arber, M.A., F.G.S., F.R.G.S., A. J. Butler, O.B.E., M.Sc., F.G.S., W. Dack, I.S.O., F.G.S., Mrs. H. K. Hawkes, M.Sc., F.G.S., J. F. Kirkaldy, D.Sc., F.G.S., H. W. Pickworth, F.R.M.S., W. S. Pitcher, B.Sc., F.G.S., H. Dighton Thomas, M.A., Ph.D., F.G.S., Miss Mabel Tomlinson, B.A., D.Sc., Ph.D., F.G.S., Miss D. E. Wisden, M.Sc., F.G.S., C. W. Wright, M.A., F.G.S.

It was moved by Dr. C. J. Stubblefield, seconded by Mr. G. Bisson and duly carried, 'That the best thanks of the Association be given the Officers, retiring Members of Council and the Auditors'.

Professor Joos Cadisch was elected an Honorary Member of the Association.

The Foulerton Award was presented to Mr. George S. Sweeting, D.I.C., F.G.S., in recognition of work of merit connected with the Association.

The President said:

One of the pleasantest duties of a President is to express his appreciation, and that of the Council, of jobs well done and I would remind our junior members that the Geologists' Association is and always has been well served by its workers, all of whom are on a voluntary basis. It is fitting, too, that these thanks should be expressed at our Annual General Meeting and here in particular I wish to thank our Treasurer and Secretaries.

There are times, however, when, due to the benefactions of old members, we may mark our appreciation in more tangible form. Today is one of them and it has been unanimously agreed by the Council that the Foulerton Award this year shall go to George Sweeting for the work he has done in and for geology and for the Geologists' Association in particular.

Mr. Sweeting, I have known you over forty years and I know that you are held in high regard by your colleagues, past and present, of Imperial College and that this regard is shared by all who come in contact with you, for you help juniors and amateurs as willingly as professionals, including professors. In this connection I would remind my listeners that Mr. Sweeting was largely responsible for seeing through the Press the last work of Professor Watts on Charnwood Forest.

Some time in the dim and distant past, George, you started work at Imperial College and the place would not be the same without you.

In 1914 you joined the Geologists' Association and were elected to the Council in 1921. In 1913, along with the late Dr. A. J. Bull and other enthusiasts, you started the Weald Research organisation and served, not only as Secretary, but took an active part in the investigations, writing several papers yourself and also directing numerous field meetings so that others could benefit from the work in its earlier stages. You have also read papers and directed excursions to other districts notably Ashover in Derbyshire and in the Malvern area.

In 1925 you were appointed Publications Secretary, a job you held until 1932 when you became Editor and you continued in that arduous post until 1946. You then pleaded for respite which we very reluctantly gave for we knew we were losing a great Editor. Moreover, not content with these jobs, you also prepared the 1920, 1930, and 1940 Ten Year Indexes of our PROCEEDINGS and anyone who has made an index will agree that, for a labour of love of this description, a lot of love is required. You have shown that love by your magnificent record of twenty-nine years' continuous and active

service on the Council and I have very great pleasure in handing to you the Foulerton Award of the Geologists' Association as a token of our appreciation of the work you have done for us and for geology.

The President then delivered his address entitled 'Roofing Materials through the Ages'.

It was moved by Dr. H. Dighton Thomas, seconded by Dr. Vernon Wilson, and duly carried 'That the best thanks of the Association be accorded the President for his Address'.

Ordinary Meeting following Annual General Meeting.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Emile Zaghlool Basta, M.Sc., Donald Robert Batie, Miss Cynthia Mavis Bazeley, Antony George Graham Bealey, Miss Janet Beckett, Philip Francis Brennan, Ivor James Colin-Thomé, David Joseph Cullen, Peter Leslie Culley, Peter Edward Fairbairn, Michael John Fleuty, Gordon Ronald Keith Hillier, Michael William Hughes-Clarke, Gwilym Morus Jones, David Malcolm Lang, Michael John Le Bas, Francis Harry Moore, B.Sc., Ph.D., James Searle Page, Neville James Price, Inkerman Theodore Pritchard, George Ormerod Rawstron, Brinley Roberts, Bernard Stonehouse and John Tempest Temple were elected Members of the Association.

Ordinary Meeting, 30 March 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Humfrey Ingram Berkeley, Frank Albert Bowater, B.A., Roderick Neville Cope, Miss Sylvia Feinsilber, Magnus Sinclair Garson, B.Sc., Harry Green, Charles Gary Hampton, Ronald D. Hawkins, Richard Alfred Irving, B.A., Donald Bertram McIntyre, B.Sc., Ph.D., F.G.S., Anthony Brandon Mills, John Gordon Orme Smart, Wilfred Dennis Wardle, Geoffrey Tudor Williams, Miss Sheila M. Walker and Colin Blair Wilson were elected Members of the Association.

The colour film, 'Paricutin—Mexico's Newest Volcano', was shown, and an introduction and commentary was given by Dr. G. F. Claringbull.

Ordinary Meeting, 4 May 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Robert Louis Aston, John Bell, B.Sc., Colin John Campbell, Miss Shirley Mae Chapman, George Edward Thomas Eyston, Brian Anthony French, Glyndwr Howell Rhys, Kenneth Spink, John Sutton, Ph.D., A.R.C.S., Miss Janet Vida Watson, Ph.D., A.R.C.S. and Russell John Wood were elected Members of the Association.

The following papers were read: (1) Mylonitisation and Cataclases in Acidic Dykes in the Inch (Aberdeenshire) Gabbro and its Aureole, by Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.R.S.E.; (2) The Influence of Rock Structures on Cliff Development around Tintagel, North Cornwall, by Gilbert Wilson, Ph.D., M.Sc., D.I.C., F.G.S.

Ordinary Meeting, 1 June 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Alan John Armstrong, Miss Marjorie Heather Bell, Miss Winifred Beatrice Bennewith, Eric Charles Blunden, William Ernest Bradford, Leslie James Frank Budd, Miss Joan Patricia Cassam, Miss Nora Olive Flynn, George Stewart Fraser, Miss Margaret Elizabeth Green, Stanley Green, Miss Margaret Frances Hancock, Miss Elsie May Heeles, Miss Dorothy Margaret James, John Lynn Jones, Miss Mary Jean Keymer, Professor E. Lehmann, Francis Alfred Meggy, John Ridding Morse, Miss Patricia Emily Pinkney, Harold Herbert Powell, Miss Valerie Christine Powell, David George Price, Miss Margaret Robertson, Mrs. Jean Helen Rose, Miss Pamela Margaret Russell, Harold Rigby Samson, Trevor Morgan Thomas, M.Sc., F.R.G.S., Thomas Edward Tompkins, Colin Whitney, Henry Wijayaratna, Miss Williamina Catherine Wilson and Herbert Newton Wright were elected Members of the Association.

The following papers were read: (1) Some Eocene Serpulids, by Arthur Wrigley; (2) A 400-foot Bench in South-Eastern Warwickshire, by G. H. Dury, M.A., Ph.D.

Ordinary Meeting, 6 July 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Edwin Hollis Adams, C.R.S.I., A.M.I.P.C., Alfred Cecil George Best, Albert Fernleigh Bluett, Raymond Wilford Clayton, David Clegg, Ronald Frederick Scott Forbes, Alan Ogilvie Gauld, Keith Ronald Greenleaves, David James Hendley, Robert Alexander John Jennings, Eric Ledgerwood, Paul Geoffrey Morris, George Leslie Morrow, Robert William Mottershead, James Arthur Noel Norton, Samuel Harry Rogers, Mrs. Diana Vivian Stebbing, Geoffrey Trollope, Malcolm Stuart Webb, Bertram George Woodland and John Gordon Wynd were elected Members of the Association.

The following paper was read: The Geomorphology of the Blean, by Miss A. Coleman, B.A.

Special General Meeting, 5 October 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

This meeting was convened by the Council for the purpose of increasing the annual subscription.

The following resolution was proposed by the President and seconded by Mr. E. Ernest S. Brown: 'That on and after 1 January 1952 the subscription be increased to one pound per annum.' After discussion the resolution was carried and Rule VIII amended accordingly.

Ordinary Meeting, 3 November 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Jack Ronald William Cheatle, Eugene Harold Charles Cotterill, John Philip Cuming, Alfred T. Grove, Miss Joyce Isabel Hill, John

Neville Hutchinson, Miss Margaret Kempthorn, Kennett Alexander Kennard, Spencer Leonard Millham, Arthur Gordon Hugh Osborn, James Osborne, James Park, John Parker, A.M.I.C.E., Robert Joseph Gray Savage, Derrick Halliwell Shaw, Cecil Henry Smith and David Yates were elected Members of the Association.

The Reunion which followed was held at the Chelsea Polytechnic, and was attended by nearly 300 members and friends. (For list of exhibits, see page 100.)

Special General Meeting, 7 December 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

The meeting was convened by the Council for the purpose of increasing the annual subscriptions of Institutions, etc. It was proposed from the chair and duly carried, that Rule XXVII be amended to read as follows:

Any Library, Museum, Scientific Society, Club, or other Public Institution may, on application, be placed by the Council on the list of Members of the Association, and shall, on payment in advance of a sum equal to that paid by Ordinary Members, be entitled to such of the publications of the Association as are delivered free to the Members, but shall not be entitled to any other rights or privileges. The Council shall have full power to grant or to refuse permission to any such applicant, and the name of any Library, Museum, or other such Institution may be removed from the List of Members by the Council at any time.

Ordinary Meeting, 7 December 1951.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Gerald David Bartram, Maurice Hugh Battey, Stanley Hay Umphray Bowie, Norman Edward Butcher, Martin Henry Cadman, Miss Nina Carroll, Miss Ida Cottier, Alfred Marshall Cubbon, Arthur George Darnley, Mrs. M. E. Dickens, R. W. Dickens, Miss Kathleen Julia Elsworth, Frederick James Fitzpatrick, Miss Audrey Getty, John Michael Hallinan, William Dodd Holmes, Derek Ralph Howlett, Miss Marjorie Johnson, Hugh Jenner-Clarke, Hans Godfrey Kugler, Miss Julia Mary Langley, Michael Anthony Paynton Latham, James Neville Leighton, John William Mercer, Roy Metcalfe, D. J. Morrish, Miss Sheila Muriel Morton, B.Sc., Dennis Platten Merrett, Roger Neves, Arthur John George Notholt, B.Sc., Kenneth Powell, George Edward Randles, Mrs. Honor Mary Randles, Peter Sidney Richards, John Hardy Smith, Miss Marjorie B. Smith, Joseph Allan Swires, Henry Sylverton, Miss Margaret Walker, James Boswell Warren, Miss T. Muriel Whitaker, M.A., James Shakespeare Wilkinson, B.A., Frank Willett, Stanley Lewis Williams and Kenneth Walter Young were elected Members of the Association.

The following paper was read: The River Ystwyth (Cards.)—a geomorphological analysis, by E. H. Brown, M.Sc.

LIST OF EXHIBITS

Geological Survey and Museum

- (1) An exhibit of native metals.
- (2) New publications.
- (3) New and reprinted geological maps.

British Museum (Natural History), Department of Geology

- (1) A technique for developing silicified brachiopods with hydrochloric acid. H. M. Muir-Wood and E. F. Owen.
- (2) The use of plastics in the preparation of fossils: a new and simplified technique.
H. A. Toombs and A. E. Rixon.
- (3) Late Devonian fishes from the Plateau Beds of Breconshire.
W. N. Croft and E. I. White.

Bennett, W. H.

Gastroliths, from the Iguanodon Pit (Weald Clay) at Ockley, Surrey.

Bottley, E. P.

- (1) Latest discoveries of rarer minerals from Ytterby and adjacent areas in Sweden.
- (2) Fine mineral crystals including the new crystallised apatites from Mexico.
- (3) New models and apparatus.

Casey, R.

Cretaceous Mollusca from Texas, California, Alabama and Tennessee.

Dollar, A. T.

The ancient platforms and strands of Lundy, Bristol Channel.

Elwell, R. W. D.

Some Dalradian rocks of N. Mayo, Ireland.

Evans, E.

Evolution of the Thames. Photographs illustrating terrace-features between the Cookham Reach and the Colne.

Goodfellow, R. F.

Lias ammonites recently collected from Whitby.

Hayward, J. F.

- (1) Geological photographs of temporary sections in the London area.
- (2) Lithological variations in the London Clay, illustrated by material from temporary sections.
- (3) Interesting geological specimens.

Marston, A. T.

'Nature the Tool-maker.' Geologically fractured flints.

Mueller, G.

- (1) The stalactitic and zoned fumaroles of the Island of Vulcano, Italy.
- (2) The alteration of the hydrocarbons of Derbyshire by mineralising solutions and intrusives.

Pocock, R. W.

Views of Auvergne.

Prentice, G. E.

- (1) Research in the Culm Measures of North Devon.
- (2) A cemented scree deposit in North Staffs.

Rivett, W. H. E.

- (1) A mammoth tooth from river gravels of the River Wey, near Ripley, Surrey.
- (2) Some reptile bones from Ockley, Surrey.

Stebbing, W. P. D.

- (1) New Zealand nephrite worked up as wood-chipping tools, but showing method of detachment from rock *in situ*.
- (2) Photographs taken on Field Meeting to French Central Massif.

Venables, E. M. and Curry, D.

Some Lower Bracklesham fossils from the *Turritella* and *Cardita* Beds, Bracklesham Bay.

Venables, E. M. and Taylor, H. E.

Fossil beetles, and other fossils from the London Clay, Bognor, collected 1950-1.

Whitten, D., Raine, G. T. and Students of Kingston Technical College

Fossils from the Wenlock Limestone, Hobbs Quarries, Longhope, Gloucester.

Wright, C. W. and Wright, E. V.

- (1) Some Lower Cretaceous cephalopod faunas from Germany.
- (2) 'Treasure hunting—highlights of twenty years collecting in the English Cretaceous.'

FIELD MEETINGS

The following field meetings took place:

6 January.—A demonstration was held at the Water Department of the Geological Survey. This was organised by Dr. S. Buchan by kind permission of the Director of the Geological Survey.

10 *February*.—By kind permission of Professors W. B. R. King and C. E. Tilley a visit was made to the Sedgwick Museum and the Department of Petrology and Mineralogy at Cambridge.

10 *March*.—A morning visit was arranged to the laboratories of Hunting Aerosurveys Limited.

22–27 *March* (Easter).—The Easter Field Meeting was held in South Wales. The time was divided between two centres, Swansea and Cardiff. Excursions were arranged in the Swansea district under the directorship of Professors Neville T. George and Duncan Leitch, and Messrs. B. Simpson and T. R. Owen. From Cardiff, Professor J. G. C. Anderson, Miss E. Richards and Mr. R. C. K. Blundell acted as directors. Mr. B. Simpson and Miss E. Richards acted as local Field Meeting Secretaries respectively.

8 *April*.—Dr. J. F. Hayward directed an excursion to the Hainault Forest area.

28 *April*.—An interesting afternoon and evening were spent making a traverse of the Southern Chilterns under the directorship of Professor H. L. Hawkins, F.R.S.

4–6 *May*.—A weekend excursion was arranged jointly with the Midland Group. Miss Hignett acted as director and Mr. A. Luaford as secretary.

11–16 *May* (Whitsun).—Under the leadership of Dr. G. Wilson, an interesting weekend was spent in the Tintagel area.

18 *May*.—A demonstration was held during the evening at the Ordnance Survey Office.

20 *May*.—Dr. J. F. Kirkaldy and Mr. W. H. E. Rivett led a party through the Mantell Country of the Weald.

1–3 *June*.—A joint-meeting with the Yorkshire Geological Society was held at Scunthorpe, Lincolnshire, under the leadership of Dr. V. Wilson.

16 *June*.—Messrs. A. G. Davis and G. F. Elliot directed an excursion to Sheppey, a locality famous for its Lower Eocene flora and fauna.

30 *June*.—A half-day excursion was led by Dr. K. P. Oakley to Swanscombe.

14 *July*.—A traverse of the Jurassic and Cretaceous Rocks of South Bedfordshire was made under the directorship of Messrs. K. E. Seal and P. E. Sells. A visit was arranged to Stewartby and lunch provided by the courtesy of the London Brick Pit Company.

21 *July*–4 *August* (Summer).—Two centres were chosen, one at Skye where excursions were led by Professor L. R. Wager and Dr. F. W.

Anderson, the other at Ardnamurchan, where excursions were held under the directorship of Drs. J. E. Richey and M. K. Wells.

12 *August*.—Messrs. J. M. Edmonds and Callomon directed an excursion in the Oxford District.

9–24 *September* (Summer).—An excursion to the Central Massif of France was held under the directorship of Professor M. Roques, and Drs. R. Lapadu-Harques and R. Michel.

15 *September*.—An excursion to study the terraces of the Middle Thames was led by Mr. and Mrs. K. R. Sealy.

29 *September*.—The Reigate area was visited under the leadership of Dr. J. F. Kirkaldy.

17 *November*.—A demonstration of Cretaceous Echinodermata was given by Mr. C. W. Wright.

21 *November*.—A repeat of the earlier demonstration to the Ordnance Survey Office was given.

14 *December*.—A demonstration, by kind permission of the chief geologist, was given at the Research Centre of the Iraq Petroleum Company.

NORTH-EAST LANCASHIRE GROUP

The following meetings and field meetings were held during 1951:

23 *February*.—Lecture, 'Our local scenery and its geological significance', by Mr. J. Ranson, A.M.I.M.E., F.G.S.

16 *March*.—Chairman's lecture, 'The geology of the SW. Highlands of Scotland', by Mr. J. Ranson, A.M.I.M.E., F.G.S.

13 *April*.—Address by the President of the Association, T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., on 'The Geological Map from Field Work to Printing'.

5 *May*.—Field Meeting, 'The Permian Unconformity at Parbold', by Mr. J. E. Carter, M.A.

11 *June*.—Joint Field Meeting, (a) 'Cadshaw Gorge', by Mr. J. Ranson, A.M.I.M.E., F.G.S.; (b) 'The Jumbles', by Mr. Mottershead.

25 *August*.—Field Meeting, 'The Cliviger Gorge', by Mr. I. A. Williamson.

22 *September*.—Field Meeting, 'The Brinscall Gap', by Mr. D. H. Learoyd, B.Sc., F.G.S.

2 *November*.—Lecture, 'The geology of Cornwall with special reference to mineralogy', by Dr. S. A. Billingshurst.

30 *November*.—Lecture, 'Lunar craters', by Mr. F. Holden, F.R.A.S.

14 *December*.—Lecture, 'The Todmorden Valley', by Mr. I. A. Williamson.

MIDLAND GROUP

The following Meetings and Field Meetings were held:

27 *January*.—'Photograph records of fossil plants collected on G.A. excursions', by A. J. Aiers.

3 *March*.—'Shale, pyrite and sulphates in coal', by A. Bray.

4-6 *May*.—Field Meeting to Welshpool. Director, Miss Hignett, B.Sc.; Secretary, A. Ludford, M.Sc., F.G.S.

14 *July*.—Field Meeting to Lawley Bank, Wellington, open-cast coal workings. Director, E. J. Anderson.

2 *June*.—Field Meeting to Frankley and Rubery. Director, Dr. F. Raw.

15 *September*.—Field Meeting to Maney Gravel Pit. Director, Professor F. W. Shotton. Tea by kind invitation of Dr. and Mrs. Parkinson.

20 *October*.—'The Pleistocene mammals of the Midlands', by Professor F. W. Shotton.

17 *November*.—'The geology of West Sussex', by E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S.

8 *December*.—Exhibition of coloured slides by A. J. Aiers, W. G. Hardie, E. D. Lacy, and I. Strachan, followed by the Christmas Party.

NORTH STAFFORDSHIRE GROUP

The following Meetings and Field Meetings were held:

11 *January*.—'The Burma Oilfields', by P. S. Keeling, B.Sc., F.R.I.C., A.R.S.M.

8 *February*.—'Problems and methods of mine surveying', by H. Ogden.

8 *March*.—'Mineral crystals and crystal-form' (retiring Chairman's address), by J. Myers, B.Sc., F.G.S.

12 *April*.—'The Millstone Grit of North Staffordshire', by F. Wolverson Cope, D.Sc., F.G.S.

10 *May*.—'The Carboniferous Limestone and Millstone Grit of the Central Pennines', by G. H. Mitchell, D.Sc., Ph.D., D.I.C., F.G.S.

7-9 *June*.—Festival Exhibition, Municipal Hall, Newcastle-under-Lyme.

22 *July*.—Field Meeting to Castleton. Leader, D. O. Thomas.

4 *August*.—Field Meeting to Butterton Dyke and Acton Pebble Beds. Leader, W. J. Adams.

8 *September*.—Field Meeting to First and Third Grits at Wall Grange and Stockton Brook. Leader, J. Myers, B.Sc., F.G.S.

11 *October*.—Annual Conversazione.

15 *November*.—‘Mineralogy through the Looking Glass’, by Dr. G. R. Rigby.

13 *December*.—‘Graptolites’, by R. Barrass, D.F.C., B.A.

DONATIONS TO THE LIBRARY DURING 1951

(The donors are the authors of the works presented unless it is otherwise stated)

AGRICULTURAL RESEARCH COUNCIL.—Soil survey of Great Britain. Report No. 3 (1951).

BAKER, W. J.—English translation of ‘Observations sédimentologiques sur la côte Vendéenne. Sédimentation littorale et estuarienne, leurs lois générales’, by A. Rivièrè (1948).

CROWN AGENTS FOR THE COLONIES.—‘Geology and physiography of the Kingston District, Jamaica’, by C. A. Matley (1951).

DAVIS, A. G.—‘The Radiolaria of the Hawasina Series of Oman’ (1950).

DAVIS, A. G. AND G. F. ELLIOTT.—‘The London Clay of Coastal Suffolk and Essex’ (1951).

FALCON, N. L. AND L. H. TARRANT.—‘The gravitational and magnetic exploration of parts of the Mesozoic-covered areas of South-Central England’ (1951).

FREEMAN, W. H. & Co.—‘A key to the common rock-forming minerals in thin section’, by C. Durrell (1949); ‘Principles of geology’, by J. Gilluly, A. C. Waters and A. O. Woodford (1951). ‘Stratigraphy and sedimentation’, by W. C. Krumbein and L. L. Sloss (1951).

GEOLOGICAL SURVEY OF GREAT BRITAIN.—One-inch Sheets (all drift)—54 (Scarborough), 139 (Stafford), 168 (Birmingham), 338 (Dartmoor Forest) and 348 (Plymouth).

GIGNOUX, M.—‘L’exercice du “métier du géologue” ’ (1951) and six other pamphlets.

- GREEN, K. G.—‘A petroleum handbook’, by the staff of the Royal Dutch-Shell Group (1933); ‘Crystallography’, by T. L. Walker (1914); ‘The Scenery of Switzerland’, by J. Lubbock (1897); also several pamphlets and maps.
- JACKSON, J. W.—‘A retrospect of twenty-five years (1925–1950)’ (1950).
- LEACH, A. L.—Thirteen pamphlets on Pleistocene geology and other subjects, by various authors.
- MICHEL, R.—‘Étude géologique du plateau de Gergovia’ (1948).
- OVEY, C. D.—‘On the interpretation of climatic variations as revealed by a study of samples from an equatorial Atlantic deep-sea core’ (1950).
- PULFREY, W.—‘Ijolitic rocks near Homa Bay, western Kenya’ (1950).
- UNIVERSITY TUTORIAL PRESS.—‘Elements of field geology’, by G. W. Himus and G. S. Sweeting (1951).

OBITUARY NOTICES, 1951

DOROTHEA MINOLA ALICE BATE, who died on 13 January 1951, in her seventy-second year, joined the Geologists’ Association in 1915. She was already by that time an established authority on the Pleistocene mammalian and avian faunas of Mediterranean islands, having started exploring the caves of Cyprus in 1901. Her most important field work in the Mediterranean area was carried out there and in Crete, the Balearics and Palestine, though she also explored and collected in numerous other parts, and at the age of sixty-eight went as far afield as Rusinga Island in Lake Victoria with Dr. L. S. B. Leakey. Her early work yielded discoveries of pigmy elephants and hippopotamus in the Mediterranean; and Palestinian collections formed the basis of one of her most important monographs: *The Fossil Fauna of the Wady-el-Mughara Caves* (1937). Her only separate contribution to our PROCEEDINGS was a short *Note on the Animal Remains from Willington* (*Proc. Geol. Assoc.*, 1926, 37, 418–19), dealing with specimens from a late Pleistocene gravel in Bedfordshire. A list of her published papers runs to some eighty titles, but she also contributed to other investigators innumerable brief notes and identifications of vertebrate remains from Pleistocene and later sites, which

are scattered through many publications in this and other countries. A good naturalist from her earliest days, she always preferred to study material of her own collecting and throughout her life combined excavation and study in the field with work in the British Museum (Natural History), with the Geological Department of which she had been associated for over half a century.

W.N.E.

LOUIS AIMÉ CAMMIADÉ was born in India in 1872. He became barrister-at-law (Middle Temple) and served in the Indian Provincial Civil Service from 1895 to 1925, attaining the rank of Chief Presidency Magistrate of Madras.

He joined the Association in 1924.

During his lifetime he was always interested in Indian archaeology and geology. His opinions were sought of, and often accepted, by eminent archaeologists and geologists (including the authorities at the British Museum). He has written several articles dealing with the 'Stone Age' and some of them were published in *Man*, *Antiquity*, *Geological Magazine*, *Man in India* and *Indian Antiquity*. Apart from this, he has left a large collection of notes and unpublished articles on implements, geology and Indian cults.

His papers were read before the British Association for the Advancement of Science in 1930 and 1931 at Bristol and London. He has also left a very large collection of stone implements which he has gathered during his service in India, some of which are in the museums at Cambridge and Bristol.

REGINALD THOMAS CORNISH, who died suddenly on 20 March 1951, at the early age of thirty-seven, gained his interest in geology whilst reading for a geography degree at King's College, London. Early in the war he joined the Meteorological Office and was later entrusted, most successfully, with a task overseas which demanded great discretion, ability and resourcefulness. After the war he was appointed to the staff of the Geography Departments of first Birkbeck College and then University College, London. Although Cornish's main interests were now meteorological, he was convinced that all those engaged in the physical side of geography must have a sound background of geology. He, therefore, joined our Association in 1948 and attended a number of its meetings and also those of the International Geological Congress. Those who knew him appreciated his quiet, genial but very solid character, and had anticipated much good work from him in his chosen field. He was married but had no children.

J.F.K.

FRANCIS CROMBIE. Born in December 1890, Francis Crombie was educated at Leith Academy and served apprenticeship as an architect. He worked with the Leith Borough Engineer and the Office of Works for a short time. During the 1914-18 war he served with the R.A.S.C., afterwards being appointed to the Works Section of the Department of Agriculture for Scotland. At the time of his death, in February last, he was Senior Architect and Surveyor for the Department in Glasgow.

In 1927 he was elected a Fellow of Edinburgh Geological Society and two years later he became treasurer, a post which he occupied for the rest of his life. He was largely responsible for the sound financial position of the Society and, with Dr. J. Adams Watson, did much for the success of the Society's centenary celebration in 1934.

MATTHEW BURNOP HODGE. By the untimely death of Matthew Burnop Hodge on 3 March 1951, geology and natural history lost a fine worker whose quiet influence will long continue to bear fruit. His scientific career commenced in the field of pure geology. Later, by apparently unfortunate chance of circumstance, he was diverted to museum curatorship, in which, however, he found his real opportunity and developed ever increasing and beneficent influence.

Educated in the Higher Grade and Secondary Schools of South Shields, he became apprenticed Chemist in Palmer's Shipyard in 1913, and subsequently with the North-Eastern Marine Engineering Company. Returning from the war he was admitted to Armstrong College, Newcastle-on-Tyne in 1919, where he graduated with Honours in Geology in 1922 and was awarded the Lebour Prize for field work. He commenced research on the field charactersitics and mineralogical composition of the Permian Yellow Sands of Durham, establishing their sand-dune origin and confirming in many respects the sagacity of the first effort in geology of Professor Sedgwick. The following year he was awarded the M.Sc. and a research studentship to continue his work. In 1925 he had the honour of being elected a Commonwealth Fellow and proceeded to the Johns Hopkins University, Baltimore, to study under Matthew and Berry. Meantime he was awarded the Ph.D. on the completion of his Durham work. At Baltimore he continued sedimentary studies on the deposits of Chesapeake Bay, as well as taking part in geological expeditions in the States. On his return, he joined Professor O. T. Jones in the Department of Geology at Manchester. There he commenced investigation of the porphyrites of Galloway.

The foregoing is sufficient explanation of the keen regret felt at the time by those who knew him that, owing to the 'slump' in geological prospects in the early thirties, he was compelled to turn from pure geology to other fields. In 1932 he was invited to join his former colleague in Newcastle, Dr. Douglas Allan, who had recently become Director of the Liverpool Museum. In 1933 he went to Halifax as

Keeper of the three museums under that authority, and for twelve years did excellent work in their development. Early in 1945 he was invited to undertake similar work as Curator of the Leeds City Museum, and two years later transferred to Leicester, so succeeding to the mantle of the famous doyen of provincial museum curators, the late Dr. Lowe.

Throughout his museum career, Dr. Hodge not only did excellent service in the development of the museums themselves, but always maintained the most cordial relations with his staffs and did much for their interest and training. In consequence, his work will long survive in many centres and will form a worthy tribute to his memory. He became Secretary to the Museums Association in 1942, continuing in that office till 1949. He was active in its counsels and contributed many valuable papers to its Journal. In 1946 and 1947 he was President of the Yorkshire Federation of Museums, and in 1949 President of the Midland Federation. He also served as a professional member of the Joint Committee of the Museums Association and the Carnegie United Kingdom Trust. In a word, he had become one of the leaders of the museum world.

He was born on 3 June 1898, and was thus only fifty-two years of age when he died. Had he survived he must have acquired still greater public fame, though in spite of himself. He was modest and reticent to a degree, but deeply respected and beloved by all who knew him. In Manchester he married Miss Marjorie Bent, by whom he is survived together with his mother and three daughters.

H.J.A.H.

COSMO JOHNS. By his death on 1 February 1951, at his residence in Sheffield, in his eighty-fifth year, Yorkshire geologists have lost another of the sturdy band of workers in the early years of this century.

Born at Swansea he was a lecturer in Mechanical Engineering at the local Technical College. Subsequently he was appointed by Messrs. Vickers, Sons and Maxim Ltd., to be Superintendent of the Siemens Openhearth Melting Furnaces at their River Don Works, Sheffield, until his retirement from active business. He later travelled extensively to Russia, India, Japan and Spain on technical missions for Vickers and their associated companies.

He joined the Geologists' Association in 1908 and became a frequent attender on the long excursions, and he had the warmest regard for the Association's work. He devoted his leisure time to the study of geology, particularly in the Skipton-Malham area, and the correlation of the Lower Carboniferous rocks. His field work was largely carried out in the North of England, and for many years he was an active member of the Yorkshire Naturalists' Union; from 1905 onwards he contributed articles to *The Naturalist* and compiled the excursion notes on the districts they visited.

Johns joined the Yorkshire Geological Society in 1904, and was secretary 1907-13, and served on the Council 1914 to 1917. He was elected a Fellow of the Geological Society in 1904. He was an active member of the Sheffield Naturalists' Club and its descendant, the present Sorby Natural History Society. On the visit of the British Association to Sheffield in 1910, Johns collaborated with C. Bradshaw and B. Hobson in writing for the British Association Handbook to Sheffield, a valuable article on the geology of Sheffield and neighbourhood. His contributions to geology covered a wide range and he left a partially completed manuscript dealing with the interior heat and age of the Earth.

In his younger days Cosmo Johns was active in sport; in later years he was keen on sailing. He acted as football critic for two national papers under the *nom-de-plume* of 'The Bard', while his interest in cricket was unabated to the end. His gift as a writer of satirical verse will be remembered by his colleagues on our excursions for their caustic and amusing stanzas no less than the poetic embellishments in the visitors' books recounting the members' achievements. Johns' personality was kindly and friendly, and he enjoyed the company of his fellow men; he never neglected to spur on his co-workers to do their best with the difficult problems he placed before them.

A.E.U.

GORDON WILLIS LEPPER was born at Folkestone in 1889. He was for a short time engaged in teaching, but in 1909 he was chosen to join a large party of geologists, led by the late Leonard V. Dalton, to carry out a geological reconnaissance in Venezuela in search of petroleum. The late Mr. Cunningham Craig met the party in Trinidad and was much impressed by Lepper, and this led to his appointment on the geological staff of the Burmah Oil Company. From 1910 to 1921 he was engaged mainly on geological exploration in Burma and India, and proved to be a very keen, conscientious and exact worker. During study-leave in London he completed the B.Sc. Honours course, and also obtained the Associateship of the Royal College of Science. He then returned to Burma, and was the Company's senior geologist in the East until his retirement in 1936. During this period many new members joined the geological staff and were encouraged and helped by Lepper's kindly leadership.

Lepper had a wide experience of the varied applications of geology to petroleum exploration and development and he acquired a very detailed and exact knowledge of the geology of Burma and adjacent parts of India. He contributed an important paper on the geology of the oil-bearing regions of Burma and Arakan to the first World Petroleum Congress in 1933.

On his retirement from the East, Lepper was appointed geological adviser to the Petroleum Division of the Ministry of Fuel and

Power, a post which he held until 1946, when he returned to the service of the Burmah Oil Company. During this period he took the greatest interest in exploration for oil in this country, and in 1938 delivered a special lecture to a large audience on 'The Search for Oil in Britain'. This was so much appreciated that it was repeated at the Northern, Birmingham, and South Wales Branches of the Institute of Petroleum.

Lepper became an Associate Member of the Institute of Petroleum in 1914, a Member in 1920, and a Fellow in 1939 when the Fellowship was instituted. He became a Fellow of the Geological Society in 1914, and a Member of the Geologists' Association in 1921; he retained his membership of these bodies until his death in September 1950.

Lepper married in 1913, and his wife died in 1929. He married again in 1930, and is survived by a widow, three daughters, and two sons.

T.D.

WILLIAM CHARLES SIMMONS was born at Southampton on 20 February 1888 and received his early training at King Edward VI School in that town, and later at Shebbear College in North Devon. In 1907 he gained a studentship to the Royal College of Science in London, of which he eventually became an Associate. He graduated with honours in geology at the University of London.

For a brief spell he served under the late Sir Thomas Holland at Manchester University. In 1911, however, he joined the staff of the Geological Survey of Great Britain and made a detailed survey of the Wirral Peninsula.

Simmons' main life-work lay, however, in tropical Africa. He was at first attached to the Land and Survey Department in Uganda but, with the formation of a Geological Survey in that province, he joined his old college colleague, E. J. Wayland, and took charge of the newly-established petrological and chemical department. His duties were of a very varied nature, including the compilation of regular seismic records, and perhaps his most notable scientific researches were those on the volcanic rocks of the Bufumbira region in South-western Uganda.

After twenty-two years' service in the tropics, Simmons returned to England and settled at Parkstone, Dorsetshire, in 1936. He now devoted his attention to a study of the natural features and flora of the Isle of Purbeck which was readily accessible, while he also took a leading part in the activities of the Bournemouth Natural Science Society, becoming its President in 1942. In his later years, however, increasing lameness crippled him severely, and he died peacefully in his sleep on 10 June last.

Simmons had wide interests, both scientific and literary. He was also an artist and photographer of ability, and in 1924 two of his films, illustrating scenes in Uganda, were shown at the Wembley Exhibition.

D.A.W.

JOHN WILLIAM TUTCHER, born in Bristol on 6 June 1858, died on 10 April 1951, in his ninety-third year, in the same city where he had lived all his life.

He was one of that relatively small band of serious amateurs who, without a systematic training, have made good in our science and to whom many—both professional and amateurs—turned for help and advice.

At the early age of twelve he was apprenticed to the trade of shoe-making and for many years he carried on a business as bootmaker in Broad Street, Bristol. Many geologists—both English and foreign—can remember conversations with him in the back premises where, while keeping one eye on the shop, he would bring out some particular fossil and discuss its correct nomenclature or deal with some wider subject in geology.

The Rhaetic and Jurassic rocks were his especial subjects and the City Museum, Bristol, is enriched by over 20,000 fossils which he collected and named with such meticulous care.

He was one of the pioneers of scientific photography and examples of his work are to be found in scores of geological publications.

In 1927 the University of Bristol awarded the degree of M.Sc. *honoris causa* and in 1924 the Geological Society of London recognised his work by a grant from the Lyell Fund.

He was a prominent member of the Bristol Naturalists' Society and served on its Council and as its President. He was elected an honorary member in 1937.

Although he was always willing to help others, he published little himself unless strongly urged to do so. His few papers are to be found in the *Proceedings of the Bristol Naturalists' Society* and the *Quarterly Journal of the Geological Society of London*. He was a constant collaborator with the late S. S. Buckman and nearly all the photographs on *Yorkshire Type Ammonites* are examples of his work.

He was one of the most modest and unassuming of men, and his kindly nature, unfailing help to beginners and old-world courtesy at all times are a treasured memory of all those who remember this grand old man.

F.S.W.

SOME JURASSIC BRACHIOPODA FROM THE LINCOLNSHIRE LIMESTONE AND UPPER ESTUARINE SERIES OF RUTLAND AND LINCOLNSHIRE

By Helen M. Muir-Wood, D.Sc., F.G.S.

[Received 7 September 1951]

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ABSTRACT.—The succession of beds of the Jurassic, Lincolnshire Limestone (Inferior Oolite) and Upper Estuarine Series of Northamptonshire, Rutland and Lincolnshire is discussed, and an account given of the probable conditions of deposition. Two new genera, *Microrhynchia* and *Weldonithyris*, and eight species of brachiopods are described, seven of which are new. Of these, six species are from the Lincolnshire Limestone, one from the Inferior Oolite of Yorkshire and one from the Upper Estuarine Series. A list of species of *Lingula* so far recorded from the English Jurassic is given.

1. INTRODUCTION

THE BRACHIOPODA described in this paper were obtained during field meetings of the Geologists' Association, held at Kettering (1938 and 1946), Stamford (1938), Grantham (1939) and Lincoln (1940); or were collected by Samuel Sharp, Mr. L. Richardson, Dr. P. E. Kent or by members of the Geological Survey.

It was originally intended to publish a description of three brachiopod species from the Lincolnshire Limestone and one from the Upper Estuarine Series as an appendix to Mr. Linsdall Richardson's Lincoln Field Meeting Report (1940), but the work was unfortunately interrupted by the war, and these species have been listed as MS. names in the reports of the field meetings already mentioned.

Only three species of Brachiopoda have previously been described from the Lincolnshire Limestone (Inferior Oolite)—*Acanthothiris crossi* by Walker in 1869 and 1870; *Parvirhynchia kirtonensis* and *Zeilleria wilsfordensis* by Muir-Wood in 1939.

My thanks are due to Mr. Linsdall Richardson for much valuable field information, also to Drs. P. E. Kent, G. A. Kellaway, F. B. A. Welch, and Prof. J. H. Taylor. I am also indebted to Mr. R. V.

Melville for the loan of Geological Survey specimens in his charge, to Mr. A. G. Brighton for permission to examine specimens in the Sedgwick Museum, Cambridge, and to Dr. P. E. Kent for the loan of his entire collection from the Lincolnshire Limestone.

2. STRATIGRAPHICAL SECTION

Examination of the Lincolnshire Limestone species so far has shown that they are distinct from those of the Inferior Oolite of the Cotteswolds (Gloucestershire), Somerset and Dorset as well as Yorkshire. Some of the specimens in the Upper Lincolnshire Limestone, Weldon Beds, are micromorphs, while many of the specimens in the overlying *Terebratula* Beds are asymmetrically developed suggesting unfavourable conditions, possibly due to a change in the normal salinity of the sea and deposition in a landlocked gulf or in an estuary.

The Lincolnshire Limestone is succeeded by the Upper Estuarine Series, or basal beds of the Great Oolite Series, when estuarine conditions seem to have prevailed at times. Marine lamellibranchs occur with rare rhynchonellids in shelly bands usually composed of broken drifted shells heaped together by currents. A *Lingula* Bed containing imperfect specimens of a new species of *Lingula*, described here as *L. kestevenensis* sp. nov. (p. 136), associated with fragmentary '*Burmirhynchia*' spp. and marine lamellibranchs was found to be a fairly constant horizon in Rutland, Northamptonshire, and Lincolnshire.

The Upper Estuarine Series of Rutland and South Lincolnshire is divided by L. Richardson (1940) into three parts:

- (1) (at base) Ironstone Junction Band at or near junction with top beds of the Lincolnshire Limestone followed by clay or sands;
- (2) Black carbonaceous shale sometimes containing plants (with roots in a vertical position of growth), heavy green clay, and stratified clays with seams of shells, and the *Lingula* Bed with *L. kestevenensis* sp. nov.;
- (3) Clay, marls, or marly limestone locally with abundant *Ostrea hebridica*. The *Kallirhynchia sharpi* Bed, forming the base of the Great Oolite proper, is frequently developed above Bed (3) (at top).

At Ketton, Rutland, the *Lingula* Bed is about 17 ft. above the base of the Upper Estuarine Series (Richardson, L., 1939a, p. 39, pl. iiA) while in S. Lincolnshire at Haydor, SE. of Ancaster, six miles NE. of Grantham, it is about 14 ft. 6 in. above the basal Ironstone Junction Band (Richardson, L., 1939b, p. 468, fig. 41). Another shelly band with '*Burmirhynchia*' sp. and *Ostrea hebridica* occurs about 4 ft. above the *Lingula* Bed at Ancaster, Lincolnshire.

The *Lingula* Bed has not so far been found north of Ancaster or south of Kettering, Northamptonshire. A shelly band with large '*Burmirhynchia*' and abundant *Ostrea hebridica*, but with no lingu-las, occurs at Cranford St. John, Northamptonshire, near the base of the much reduced Upper Estuarine Series.

The sequence of beds of the Lincolnshire Limestone and the precise age is still imperfectly understood owing to lack of good sections and the great amount of local variation in lithology and thickness of beds due partly to submarine erosion.

A generalised sequence of beds of the Lincolnshire Limestone compiled from L. Richardson's four field meeting reports is set out below in emended form:

- | | |
|---------------|---|
| Lower
Beds | <p>Underlying Lower Estuarine Series (<i>murchisonae</i> Zone) or Northamptonshire Ironstone (<i>scissum</i> Subzone) at base</p> <p>1. Blue Beds including Collyweston Slate Beds at base with <i>Ger-villella acuta</i> and <i>Pinna cuneata</i> and clay bed above with <i>Serpulae</i> (<i>S. deplexa</i>, <i>S. tetragona</i>) and small <i>Ostrea</i>.</p> <p>2. Silver Beds, limestones containing <i>Nerinea</i> at base, <i>Ptygmatis cotteswoldeae</i>- and <i>discites</i>-zone ammonites in lower part. <i>Pinna</i> Bed above.</p> <p>3. Cementstones, grey argillaceous limestones [with new terebratulid species] = Kirton Beds in part of North Lincolnshire. Corals (rather common) and lamellibranchs.</p> <p><i>Acanthothiris crossi</i> Bed near top [with new terebratulid].</p> |
| | LITHOLOGICAL CHANGE |
| | <p>4. Ancaster Freestone—grey to yellow oolitic limestone, contains coral bed. Kirton Cement shale in North Lincolnshire with <i>Parvirhynchia kirtonensis</i> Muir-Wood. Wilsford Coral Bed near Ancaster with <i>Zeilleria wilsfordensis</i> Muir-Wood, and Castle Bytham coral bed.</p> |
| | PLANE OF EROSION |
| Upper
Beds | <p>5. Great Ponton Gastropod Beds = Weldon Beds with Barnack Rag, S. of Stamford, Lincolnshire (containing <i>Weldonithyris weldonensis</i> and <i>Microrhynchia barnackensis</i>, both gen. and spp. nov., described in this paper) = Ancaster Rag = Clipsham Beds.</p> <p>6. <i>Amberleya</i> Bed with <i>A. ornata</i> [= <i>Turbo gemmatus</i> of Lycett].</p> <p>7. Great Ponton <i>Terebratula</i> Beds [with <i>Weldonithyris elongata</i> and <i>W. pontonensis</i> spp. nov. (p. 134) described in this paper] and <i>Lima</i> (<i>Plagiostoma</i>) <i>bellula</i>.</p> <p>Ironstone Junction Band of Upper Estuarine Series at top.</p> |

Ammonites have so far only been found in the Silver Beds (Bed 2 of above section), and in beds of uncertain horizon at Greetwell, near Lincoln, in quarry near the Bowling Green Inn on Wragby Road, and quarry NW. of Greetwell Hollow Farm, from eight to twelve feet above base of limestone; at Grantham about five feet from base of limestone in excavation for Spittlegate Hill Reservoir (Musgrave, A. E., 1936), and from the quarry at Waltham Station and possibly eight feet above base of limestone in the Barnstone Cement Company's quarry. All the ammonites indicated *discites* Zone of the Middle Inferior Oolite (Kent, P. E. and F. T. Baker, 1938).

The Upper Lincolnshire Limestone may, therefore, be Upper Inferior Oolite, although no correlation can be made so far with beds of that age.

P. E. Kent's (1941) sequence of these beds is generally similar

to that already quoted, but the name 'Little Ponton Beds' is substituted for 'Silver Beds' and the Weldon Beds are included in the Hibaldstow Beds (= Ancaster Beds) as forming the lowest beds of the Upper Lincolnshire Limestone. Above this in his sequence come the Great Ponton Gastropod Beds, the Great Ponton *Terebratula* Beds and, finally, the *Terebratula* Bed of Houghton Hill, Grantham, at the top—the two last named being correlated with the Upper Inferior Oolite while the beds below are said to be equivalent to Middle Inferior Oolite.

The study of the brachiopods so far has shown, however, that the Weldon Beds are the same age as the Great Ponton Gastropod Beds, and younger than the Ancaster Freestone and its equivalents. It is doubtful also whether the *Terebratula* Bed at Houghton Hill, which contains several new species, does actually belong to the Upper Lincolnshire Limestone. Kent, in a later paper (Swinnerton, H. H. and P. E. Kent, 1949), groups together the lower beds of the Lincolnshire Limestone as Kirton Beds with overlying Hibaldstow or Ancaster Beds.

The much-reduced succession in the southern part of the outcrop in the Kettering district of Northamptonshire is described in the 1946 Field Report by Professors S. E. Hollingworth and J. H. Taylor. The Weldon Beds of the Upper Lincolnshire Limestone with *Weldonithyris weldonensis* and *Microrhynchia barnackensis* spp. nov. (pp. 131, 125) rest with strong unconformity either on the Lower Lincolnshire Limestone, from which the *crossi* Bed is absent, or on the underlying Lower Estuarine Series or Northamptonshire Ironstone. The channelling of the Lincolnshire Limestone in this district is described in detail by Professor Taylor (1947) and the Weldon Beds are said to be preserved in discontinuous channels or elongated basins with an ENE.-WSW. trend, cut in the underlying beds. From their general form and the well-developed current-bedding, these channels are thought to be submarine in origin and to be the result of tidal or current action. The southern limit of the Lincolnshire Limestone extends from near Maidwell through Kettering, Northamptonshire, towards Oundle with an ENE.-WSW. trend, but there is no evidence of a shore-line facies.

The succession in the northern end of the outcrop in Lincolnshire is described by Dr. V. Wilson (1948) as consisting of:

- (1) (at base) Blue Beds locally resting on Northamptonshire Ironstone.
- (2) Silver Beds with *discites* Zone ammonites.
- (3) Kirton Cementstones with *Acanthothiris crossi*, terebratulids, lamelli branches and coral beds.
- (4) Ancaster Freestone with local coral beds.
- (5) Ancaster Rag with small rolled gastropods = Hibaldstow Oolite north of Lincolnshire, at top of section.

In the north of Lincolnshire, the Santon Oolite is developed between the Lower Estuarine Sandstone and the Kirton Beds.

These generalised sections will be sufficient to show the difficulties experienced in attempting any correlation from one locality to another. The only bed traceable through the greater extent of the outcrop is the *Acanthothiris crossi* Bed which comes in just north of Stamford, Lincolnshire. At first this species is limited to one definite band, but north of Lincoln at Kirton-in-Lindsey it occurs in the Kirton Shale and again in the overlying *crossi* Bed and, finally, in north Lincolnshire at Appleby, near Scunthorpe, it ranges through ten feet of the Kirton Cementstones. A second species of *Acanthothiris*, not yet described, occurs in borings in the South Stoke district of Lincolnshire, while the *Acanthothiris* occurring in the Cave Oolite of Brough, Yorkshire, is described here as a new species (*A. broughensis* sp. nov. (p. 123)). A fourth larger species, at present also incorrectly known as *A. crossi*, occurs in the Whitwell Oolite (Inferior Oolite), of Crambeck, Yorkshire, and was figured by J. Phillips (1875, pl. 9, fig. 18).

Five other new species, two rhynchonellids *Microrhynchia barnackensis* and *M. pontonensis*, gen. and spp. nov. (pp. 125, 128), and three terebratulids, *Weldonithyris weldonensis*, *W. elongata* and *W. pontonensis*, gen. and spp. nov. are described (pp. 131, 134) from the Inferior Oolite, upper beds of the Lincolnshire Limestone, in the systematic part of this paper. *M. barnackensis* occurs in the Weldon Beds and Barnack Rag of Northamptonshire and Huntingdonshire and in the Gastropod Beds of Little Ponton, Lincolnshire. *M. pontonensis* occurs in the Great Ponton *Terebratula* Beds (= the 'Top Beds').

One species of *Lingula* (*L. kestevenensis* sp. nov.) is described (p. 136) from the Great Oolite, Upper Estuarine Series.

Investigation of the internal structure of the species described has been by longitudinal and transverse sections (Muir-Wood, H. M., 1934 and 1936) by means of the Croft parallel grinding instrument designed by Mr. W. N. Croft (1939) of the Dept. of Geology, British Museum (Natural History).

3. SYSTEMATIC DESCRIPTIONS

(a) SPECIES FROM THE LINCOLNSHIRE LIMESTONE

Family RHYNCHONELLIDAE

Genus: ACANTHOTHIRIS d'Orbigny, 1850

Acanthothiris crossi (J. F. Walker)

Plate 5, figs. 10 a-c, 12 a-c; Text-figs. 1 a-d

1869. *Rhynchonella crossi* J. F. Walker, p. 215.

1870. *Rhynchonella crossi* J. F. Walker, p. 562, fig. 9.

1878. *Rhynchonella crossi* Walker: Davidson, p. 223, pl. xxvii, figs. 17, 17a, 17b.

1889. *Acanthothyris crossi* Walker: J. F. Walker, p. 55.

1948. *Acanthothyris crossi* (Walker): V. Wilson, p. 32, fig. 10.

Syn. *Rhynchonella crucis* J. E. Cross, MS.

Diagnosis. *Acanthothiris*, about 8 mm. long, 8 mm. wide, and 5 mm. thick, approximately circular in outline, biconvex with well-defined prominent median fold in brachial valve and narrow sinus in pedicle valve. Ornament of 12–14 narrow sub-rounded costae extending nearly to umbo, 2–4 on fold and 2–3 in sinus, with irregularly developed bifurcations or intercalations. Spine-bases on costae numerous on anterior half of shell. Apical angle 100° .

Type-specimen. The single specimen, figured by J. F. Walker (1870, fig. 9), from the Inferior Oolite of Appleby Brigg, Lincolnshire, and stated to have been presented to the British Museum (Natural History), is not preserved in the Walker Collection. One of the five specimens, labelled by Walker as 'Types' from the same locality, is, therefore, designated and figured as lectotype. (B.31327.)¹

Material and Locality. *Acanthothiris crossi* Bed, near top of Lower Lincolnshire Limestone, *discites* Zone; Kirton Beds of north Lincolnshire.

Localities (under counties listed from south to north):

Rutland: Trial Pit, Little Pits Quarry; west end of Clipsham Old Quarry; in borings at Stretton.

Leicestershire: *crossi*-Bed, Croxton Kerrial, eight miles NE. of Melton Mowbray.

Lincolnshire: Stamford (*vide* Sharp, S., 1873); Little Bytham Parish Pit; Lower Coral Bed, Castle Bytham; *crossi* Bed, Stanton Limestone Quarry, South Witham; quarry NW. of Scottlethorpe Grange, three miles west of Bourne; Grims-thorpe, NW. of Bourne; ESE. of Skillington Church; SSW. of South Stoke Church and opposite Stoke House, Stoke Rochford; Little Ponton; Kirton Beds, well in quarry NW. of church, Newton, eight miles east of Grantham; section opposite Longwood Quarry, Blankney; Green Man Wood Quarry, Dunston; Dunston railway-cutting, N. of station, SE. of Lincoln; Nocton and Washingborough, SE. of Lincoln (*vide* Kent, P. E., 1941, p. 54); excavations for foundations of boiler-house, St. Giles School, Lincoln; Kirton Beds, top of Greetwell Hollow Quarry, Lincoln; ditch-section, Normanby, 10 miles N. of Lincoln; from borehole, $\frac{1}{2}$ mile W. of Glentham, 12 miles NNE. of Lincoln; from limestone with corals, in lower part of Kirton Clay, Alpha Cement Co. quarry west of main road; and from upper *crossi* Bed, top bed of Kirton Beds above Kirton Clay, Kirton-in-Lindsey; road cutting, Low Santon, near Appleby (= Appleby Brigg of J. F. Walker Collection); bed of New River, Ancholme, N. of Bridge Street, Brigg; Kirton Beds, Dragonby, near Appleby; Broughton Woods, N. of Brigg.

¹ Unless otherwise stated all figured specimens are preserved in the British Museum (Natural History). B. or BB., followed by figures, represent the registration numbers.

Specimens have been examined in the British Museum (Natural History), in the Geological Survey Museum Colln., London, and in P. E. Kent's Collection.

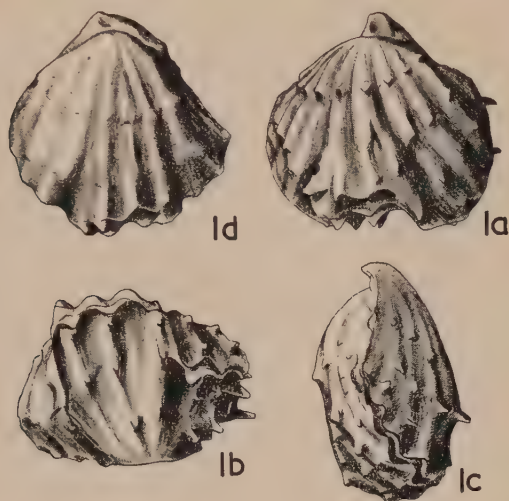


FIG. 1.—*Acanthothiris crossi* (J. F. Walker). (a-c) Lower Lincolnshire Limestone, *discites* Zone, *crossi* Bed, Stanton Limestone Quarries, South Witham, Lincolnshire. B.M. (BB.11272). (See also Plate 5, figs. 10 a-c.) (d) Same horizon. Appleby Brigg, Lincolnshire. B.M. (BB.6301). Topotype. To show character of costation and rows of spines. All $\times 4$ approx.

Previous Record. This species was recorded by Judd (1875, p. 158) and Sharp (1873, p. 252) in a brittle limestone from below the Free-stone Bed of the Lings, Stamford, about 29 ft. above the base of the Lincolnshire Limestone, but no specimens have been seen from this locality. Ussher (1888, p. 182) recorded *A. crossi* from Greetwell railway-cutting, and from Nettleham Road quarry, near Lincoln. It is probable that the specimens recorded by Judd (1875, p. 151) from Great Weldon and Kings Cliffe, Northamptonshire, and by Sharp (1873, p. 265) from Wansford and from the Barnack Rag of Barnack, Northamptonshire, should be identified as *Microhynchia barnackensis* sp. nov.

Cross (1875, p. 121) recorded *R. crossi* from the Lincolnshire Limestone above the Santon Oolite from the neighbourhood of Appleby, NW. Lincolnshire.

The specimens recorded by Drake and Sheppard (1909, p. 65) from the Millepore Bed of Brough, Yorkshire, should be identified as *Acanthothiris broughensis* sp. nov. (p. 123).

Dimensions. Lectotype; maximum length 8 mm. approx., maximum width 8 mm., maximum thickness 8.5 mm. Specimen BB.6301; maximum length 7.5 mm., maximum width 7.8 mm., maximum thickness 5 mm. Specimen BB.6310; maximum length 6.5 mm., maximum width 6.5 mm., maximum thickness 5 mm.

Description. (a) *External Characters.* In the earliest growth-stages the shell is circular in outline but it rapidly increases in breadth until the adult stage when the outline again becomes approximately circular. The posterior portion of the brachial valve is slightly sulcate and the pedicle valve convex. A shallow sinus is developed in the pedicle valve at a distance of about 3 mm. from the umbo. The brachial valve becomes increasingly convex in the later growth-stages and a median fold is developed about 3.5 mm. from the umbo. The median fold and sinus increase in height and depth respectively in the gerontic stage and are well demarcated from the lateral slopes. The linguiform extension of the pedicle valve is about 3.5 mm. in length and tapers very slightly towards the brachial valve. In the adult shell, the brachial valve is considerably more convex than the pedicle valve. The umbo is acute and tapering, erect in young shells but incurved and separated from the brachial valve in the adult. The beak-ridges are subangular and the foramen hypothyrud. Complete deltidial plates were not observed in any specimen, but one plate preserved in a specimen from Appleby Brigg indicated that they are disjunct.

The shell is ornamented by narrow, rounded, prominent costae which are developed in both valves about 2 mm. anterior to the umbo. From 6 to 8 costae are developed posteriorly, but two or more of these may bifurcate and irregularly developed intercalated costae may increase these numbers to 12 or 14 at the anterior margin in the adult. The arrangement of the costae, however, varies considerably. One or both of the costae ornamenting the median fold posteriorly may bifurcate, but only one of the resultants remains as a rule on the summit of the fold. Growth-lines are prominent on well preserved specimens but, owing to decortication of most of the material, are rarely observed. Three or four spine-bases spring from the summit of each costa on the anterior half of the adult shell, but the spines are rarely preserved intact. There is a tendency for a concentric arrangement of the spine-bases along growth lamellae. Detached spines, from 4-10 mm. in length, are frequently observed and specimens from South Witham with spines preserved show that these must have extended at a low angle to the shell surface.

(b) *Internal Characters.* The muscle-scars of both valves are obscure. In the brachial valve a median septum, 2.5 mm. in length, is usually seen through the test, while the hinge-sockets appear as dark lines meeting at the umbo at an angle of 90°. The dental lamellae, seen through the test of the pedicle valve, diverge from the umbo at

an angle of 40° . Investigation of the internal structure by means of transverse sections shows that it is similar to that observed in *A. midfordensis* and *doulingensis* Richardson and Walker, and *A. powerstockensis* Buckman and Walker (ref. Muir-Wood, H. M., 1936).

Remarks. *A. crossi* is distinguished from other British species of *Acanthothiris* by its small dimensions, prominent median fold, deep sinus, and by its irregularly developed costae which do not extend to the umbo. The specimens from Brough, Yorkshire, referred to *A. crossi* by J. F. Walker, and also by Hudleston and Walker (1876), are more finely costate, having on an average 20 costae in the adult shell, and lack the prominent median fold and deep sinus of *A. crossi*. These Brough specimens from the Cave Oolite are described as a distinct species, *Acanthothiris broughensis* sp. nov.

Specimens, usually identified as *A. crossi* from the Whitwell Oolite of Crambeck, Yorkshire, and preserved in the British Museum (Natural History) (B.31272, 31273), are considerably larger than *A. crossi* and have a more convex brachial valve, more numerous costae, with a well defined median fold and sinus bearing 5-6 costae. The linguiform extension in this form is 5 mm. in length and is often squarely truncate. It cannot be identified with any of the species described by Buckman and Walker (1889) or with *A. globosa* from the *buckmani* Grit of the Cotteswolds, and appears to be very similar to *A. tenuispina* Waagen (1867), described from the *sowerbyi* Zone of Gingen, Württemberg.

This Crambeck species is presumably the form from the Whitwell Oolite referred to as *A. crossi* by V. Wilson (1948, p. 37), by Hudleston and Walker (1876, pp. 3, 6) and by Fox-Strangways (1892, p. 215) from the Millepore Bed.

The specimens recorded by Kent (1941, p. 57) as close to or identical with *A. crossi* from Newbald, Yorkshire, in thin shale at the base of the Cave Oolite, have not been examined and it is uncertain whether they belong to *A. broughensis* sp. nov.

A third small species of *Acanthothiris*, preserved in the Geological Survey collections (B.W.1502-07) from a boring between South Stoke and Bassingthorpe, Lincolnshire, in a bed about 36-46 ft. above the true *crossi* Bed, differs from *A. crossi* in its slightly larger dimensions, less prominent and slightly more numerous costae which extend to the umbo and become less defined near the anterior margin, and in the lack of median fold and sinus. About a dozen imperfect examples of this species were examined from this one locality where they were associated with *Zeilleria wilsfordensis* Muir-Wood.

A note on the label of Davidson's specimens of *A. crossi* from Appleby Brigg (BB.6301-9) states that the specimens had been presented to him by the Rev. J. E. Cross who proposed the name *Rhynchonella crucis* for this species. Walker's name '*R.* *crossi*' has priority over *R. crucis* which was not described by Cross. *R. crucis*

is, however, mentioned by Sharp (1873, p. 254) as occurring at Tinkler's Quarry, Stamford.

Rothpletz (1886, p. 93) included the species *A. crossi* in his *Gruppe der Spinosen*, and suggested that it was similar to *A. oligacantha* (Branco) from the *sowerbyi* and upper *murchisonae* Zones of Lorraine (from St. Quentin near Metz). Branco's species (1879, p. 127, pl. 6, fig. 7), which he compared with Quenstedt's figure of *Terebratula spinosa* (1870, pl. 39, fig. 52), from the Braun Jura γ of Jungingen, Württemberg, appears to be rather similar to *A. crossi* in shape and number of costae, but to be a slightly larger shell (length and width 10 mm.) with fewer and more symmetrically arranged spines and fewer bifurcations and intercalated costae. No example of this species has, however, been examined from Lorraine, though some crushed specimens (B.38147) from the *sowerbyi* Zone of the Freiburg district of Württemberg may belong to Branco's species.

Haas and Petri (1882, pl. 6, fig. 5) identified incorrectly as *A. crossi* a form from the *sowerbyi* Zone of Bastberg, near Buchsweiler, Lower Alsace, and included in their description the large form figured as *R. spinosa* by E. Eudes-Deslongchamps (1857, pl. 5, fig. 1) from an unknown horizon of the Inferior Oolite of Calvados. The Alsace form is longer, 11–12 mm. long and 16–17 mm. broad, and more finely costate than *A. crossi*.

The specimens figured by Greppin as *A. crossi* (1900, p. 180, pl. 19, figs. 14, 15) from the *humphriesianum* Zone of Sulz, near Muttentz (Bâle district), appear to be slightly larger than *A. crossi*, to have fewer spines which are arranged in one or two concentric rows and anteriorly placed, and to be ornamented by simple costae radiating out from a short distance below the umbo.

This species is probably a later development than *A. crossi*, but *A. oligacantha*, *A. crossi* and the Sulz form may be grouped together as possibly related species.

The *Acanthothiris crossi* Bed forms a well-marked horizon which is traceable from the north of Stamford, Lincolnshire, to North Lincolnshire. South of Stamford the *crossi* Bed is cut out by an unconformity and Weldon Beds may rest directly on the Northamptonshire Ironstone, as at Great Weldon, or on Lower Estuarine Beds at Wansford, six miles SE. of Stamford. The typical *crossi* Bed consists of a hard compact limestone, from which complete specimens can rarely be extracted. In the northern part of the county, the species appears to range through the Kirton Beds, and, at Kirton-in-Lindsey, flattened specimens of *A. crossi* occur in the Kirton Clay, while normally preserved specimens occur in a limestone bed at the top of the Kirton Beds.

The original report about this species (Walker, J. F., 1869, p. 215) was as follows:

Mr. Walker also exhibited some Rhynchonellae sent to him by the Rev. J. E. Cross, M.A., which are supposed to be an extreme variety of *R. spinosa*,

from which they differ in their smaller size, in having fewer plaits on the surface of the valves, and by the greater distance of the plaits from each other, seldom having more than twelve plaits on each valve. They also appear to differ from *R. spinosa* in having a mesial fold of generally three plaits. The hardness of the rock makes it difficult to obtain perfect specimens, but in the specimens he exhibited the beak appears to be more incurved than in the typical specimens. He proposed the name of *R. crossii* for this variety. Mr. Cross also sent him some fine specimens of *Terebratula submaxillata*, and some *Terebratulæ* which he had identified as *T. buckmanni* [sic] and *T. sphaeroidalis* and *Rhynchonella subtetrahedra*. All these specimens are from the Inferior Oolite of Appleby, near Brigg, Lincolnshire.

The other four species listed from Appleby have not yet been described.

***Acanthothiris broughensis* sp. nov.**

Plate 5, figs. 11 a-c, 13-15

Syn. *Acanthothyris crossi* Auctt. pars.

Diagnosis. *Acanthothiris*, about 8 mm. long, 8 mm. wide, and about 6 mm. thick, approximately circular in outline, biconvex with scarcely perceptible median fold and sinus. Anterior commissure with slight wave (uniplica). Ornamented by about 20 fine anteriorly bifurcating costae, extending to within 2 mm. of umbo. Spine-bases in four concentrically arranged rows. Apical angle 110°.

Type specimen. Holotype from the Inferior Oolite, Cave Oolite, Brough, Yorkshire, in J. F. Walker Collection, British Museum (Natural History), (BB.11294). Paratypes from the same locality (B.19806 and BB.11293).

Material and Locality. Seventeen specimens from the Inferior Oolite, Cave Oolite, Brough, Yorkshire.

Dimensions. Holotype; maximum length 7.8 mm., maximum width 8.1 mm., maximum thickness 6.4 mm.

Description. (a) *External Characters.* The shell is approximately circular in outline in all growth-stages. The umbonal region of the brachial valve rapidly increases in convexity and there is no median fold. The pedicle valve is less convex than the brachial valve with slight median flattening or sulcation anteriorly, but with no true sulcus. The anterior commissure is incipiently uniplicate and the lateral commissure is ventrally curved. In some specimens the anterior part of the pedicle valve is curved dorsally at a sharp angle to the posterior part of the valve. The umbo is short and acutely tapering, sub-erect to slightly incurved, but well separated from the brachial valve. The foramen is hypothryid and the deltidial plates disjunct.

The shell is ornamented by about 10 to 14 fine costae posteriorly and increasing by bifurcation to about 20 anteriorly.

(b) *Internal Characters.* Not investigated owing to the poor state of preservation of specimens. In the brachial valve the median septum

is 3 mm. long in a brachial valve 6.5 mm. in length, while the dental lamellae seen through the test diverge at an angle of 30° .

Remarks. *A. broughensis* differs from *A. crossi* in its slightly larger dimensions, lack of median fold and sinus, finer and more numerous costae, more regularly arranged spines. It differs from the species of *Acanthothiris* (probably = *A. tenuispinosa* Waagen) occurring in the Whitwell Oolite and Millepore Limestone of South Cave and Crambeck, Yorkshire (ref. Phillips, J., 1875, pl. 9, fig. 18, from [South] Cave, Yorkshire) by its smaller dimensions, more regularly arranged spines, less prominent costae which do not extend to the umbo as in the Crambeck form.

A. globosa Buckman (1918, pl. 19, fig. 25) from the Middle Inferior Oolite, *buckmani* Grit, Post-discites Subzone of the Cotteswolds, is a larger, more globose form ornamented by about 18–22 costae extending to the umbo and rarely bifurcating, with 4–6 on the median fold. There are from 6–8 spines on each costa arranged concentrically along growth-lines. The umbo in this form is much produced and incurved over the brachial valve.

Genus: MICRORHYNCHIA gen. nov.

Diagnosis. Shell small, rarely sulco-convex in neanic stage, becoming bi-convex, everted, median fold and sinus often ill-defined. Hypothyrid to just mesothyrid. Beak sub-erect to slightly incurved. Deltidial plates conjunct in adult. Shell smooth to finely costate. No pedicle collar developed. Dental lamellae diverging at angle of about 60° . Median septum extending about half length of valve. Crura calcarifer. In transverse sections cardinal process and septalium absent. Hinge-plates almost indistinguishable from inner socket-ridges and extending ventrally at angle of 45° to low median septum.

Genotype. *M. barnackensis* sp. nov.

Species (at present recognised). *M. barnackensis* sp. nov. (p. 128), *M. pontonensis* sp. nov. (p. 000).

Range. Jurassic. ?Upper Inferior Oolite, Lincolnshire Limestone.

Remarks. These small species from the Lincolnshire Limestone cannot be assigned to any of the Jurassic genera described by Buckman (1918); they differ from *Holcorhynchia standishensis* S. S. Buckman, type-species of *Holcorhynchia* from the Upper Lias, Whitbian of Gloucestershire, in the conjunct deltidial plates and mesothyrid beak ridges, also in the more globose brachial valve which is rarely sulcate posteriorly; in *H. standishensis* the brachial valve is sulcate in all growth-stages. The internal characters of *Holcorhynchia* are unknown, and no material was available for examination.

The general form and ornament of *M. barnackensis* distinguish it from other semiplicate forms described by Buckman, e.g. *Piaro-*

rhynchia, *Tropiorhynchia* and *Cuneirhynchia*, all of which are at present only known from the Lias.

Description. *Internal Characters.* Owing to the coarse oolitic matrix-infilling of shells of this species, it was not possible to make a perfect preparation to show internal characters. The proximal part of the crura is preserved in specimen (BB.11296) figured on Plate 5, fig. 9. The crura in this specimen are sub-parallel plates, 0.7 mm. long, which extend as a continuation of the hinge-plates towards the pedicle valve. The whole plate is slightly curved upwards towards the umbo, while the under surface of each plate is concave anteriorly. In a longitudinal section, which was partially excavated by dissecting needle, one crus was seen in specimen (B.97753) and figured in Plate 5, fig. 5. In this specimen the posterior broad proximal part of the crus is continued as a fine almost medianly curved ridge, about 1 mm. in length, which tapers to a thread-like extremity. The whole crus approximates in outline to what has been described as calcarifer (Muir-Wood, H. M., 1934; 1936). The hinge-plates were only seen in transverse section and are scarcely demarcated from the inner socket-ridges, and the plates extend at an angle of about 45° to the low median septum to which they are not attached. The teeth are broad, finely crenulated and fairly deeply inserted in the hinge-sockets. Accessory articulation, by means of denticles and sockets on the outer socket-ridges, is developed as in other Jurassic rhynchonellid genera. The dental lamellae are attached to the shell floor posteriorly, but become detached at an early stage and are only traceable in contact with the teeth for about 0.7 mm. from the umbo. The median septum in the brachial valve is low and rather broad and extends about half the length of the brachial valve.

The muscle scars were not observed in either valve.

***Microrhynchia barnackensis* sp. nov.**

Plate 5, figs. 5, 6 a-d, 7 a-c, 8 a, b, 9; Text-figs. 2 a-c, 3

Syn. *Rhynchonella crossi* Auctt. pars.

Diagnosis. *Microrhynchia* about 6 mm. long, 6 mm. wide and 4.5 mm. thick, subtrigonal in outline, biconvex, brachial valve rarely posteriorly sulcate, median fold and sinus ill-defined, linguiform extension short, tapering. Posterior third of shell smooth, costae about 12-20 with 5-7 on fold, fine, separated by sulci of approximately same width. Intercalations and bifurcations rarely developed. Growth-lines forming regular ornament. Umbo erect to slightly incurved, hypothyril or just mesothyril. Apical angle about 100° .

Type-specimen. Holotype from the ?Upper Inferior Oolite, Upper Lincolnshire Limestone, Barnack Rag development of Weldon Beds of Bonemills Quarry, 9/10th mile W. 15° S. of church, Wittering,

Northants, and preserved in the British Museum (Natural History) (BB.9718). Paratypes from the upper part of Weldon Beds, Great Weldon Stone Quarry, Northamptonshire (B.97752, 97753); and Great Ponton Gastropod Beds, Great Ponton, Lincolnshire (BB.11295).



FIG. 2.—*Microrhynchia barnackensis* sp. nov. Paratype. Upper Lincolnshire Limestone. Weldon Beds. Great Weldon Stone Quarry, Northamptonshire. B.M. (B.97752). (a) Brachial valve view. (b) Anterior view. (c) Lateral view. $\times 4\frac{1}{2}$. (See also Plate 5, Figs. 7 a-c.)

Material and Locality.

Numerous specimens from the Upper Lincolnshire Limestone, Weldon Beds, Barnack Rag, and Great Ponton Gastropod Beds. Localities listed from south to north along outcrop.

Northamptonshire. Base of Weldon Beds, Pipewell waterworks well; and pit S. of Pipewell to Oakley Road, ESE. of Pipewell Hill; Weldon Grange Quarry; Great Weldon Stone Quarry; quarry $\frac{1}{2}$ mile SSE. of bridge at Kings Cliffe; near Peterborough (obtained from Wood Quarry, Stibbington, according to L. Richardson); just above Weldon Freestone, Walls Quarry, W. end of Wansford Tunnel; quarry 1 mile SW. of Thornhaugh church; Bonemills Quarry, Wittering.

Lincolnshire. Stamford; Gastropod Beds, Great Ponton and ?Little Ponton.

Specimens are preserved in the British Museum (Natural History); Geological Survey Museum; Sedgwick Museum, Cambridge; Scunthorpe Museum; Peterborough Museum, and Dr. P. E. Kent's collection.

Dimensions. Holotype; maximum length 5.5 mm., maximum width 5.7 mm., maximum thickness 4.1 mm. Paratype (B.97752); maximum length 5.5 mm., maximum width 5.9 mm., maximum thickness 4.2 mm.

Description. (a) *External Characters.* In early growth-stages the brachial valve is flattened or with shallow posterior sulcation but it rapidly increases in convexity and becomes globose in some individuals. The median fold is scarcely raised above the level of the flanks

except in the gerontic stage. The pedicle valve is slightly convex in early growth stages, the convexity increasing with age but never equalling that of the brachial valve. A shallow median sinus is developed in the pedicle valve or the valve may only be medianly flattened. A short linguiform extension is developed, tapering towards the brachial valve, but rarely exceeding 2 mm. in length. The median



FIG. 3.—*Microrhynchia barnackensis* sp. nov. Upper Inferior Oolite, Upper Lincolnshire Limestone, Gastropod Beds, Great Ponton, Lincolnshire. B.M. (B.15856). A series of nine transverse sections through the posterior part of the shell. Sections 2, 3, 4 at distances of approximately 0.2 mm. apart, and 5-9 at distances of 0.1 mm. apart. Section 1 was ground 0.2 mm. below the apex of the umbo. All sections $\times 6$. The hook-like form of the united hinge-plates and inner socket-ridges is unlike the hinge-plates of any other rhynchonellid genus so far examined. No septalium or septalial plates are developed. No traces of internal structure were seen after section 9.

fold and sinus may be asymmetrical. The shell tends to thicken along the anterior commissure. The deltidial plates are disjunct in early growth-stages but may be conjunct in the adult, and the angular beak-ridges are hypothyrid or just mesothyrid.

The shell is ornamented by a variable number of costae normally from 16-20, though some specimens have as few as 12, none of which extend back to the umbo. There is some variation in the extent of the posterior smooth portion of the shell. In some specimens the costae extend practically to the umbo, while in others the posterior third or rarely three-quarters or half of the shell is smooth. These variations all occur in specimens collected from one locality and from the same shell-band. There are, as a rule, 4-6 costae on the median fold and 4-5 in the sinus. Intercalations and bifurcations may occur in shells

in which the costae extend nearly to the umbo. The growth-lines form a regular transverse ornament in well preserved specimens. The dimensions rarely exceed those quoted above though specimens up to 10 mm. in width and 9 mm. in length occur rarely in a flaggy shelly limestone in the Great Weldon Stone quarries (associated with normally developed specimens of *Weldonithyris weldonensis* sp. nov.). It is not proposed to describe these larger specimens as a distinct species since the smaller are largely micromorphs or young individuals.

(b) *Internal Characters.* As for genus.

Remarks. So far no specimens of *Microrhynchia* have been found in the Inferior Oolite of other areas in this country, or elsewhere in Europe.

A closely allied species of *Microrhynchia* having similar internal characters, occurs in the Cementstones, Dean and Chapter Pit, Lincoln. The only specimen available for comparison had fewer costae, 14 instead of about 16–20 in *M. barnackensis*, and these were only developed on the anterior third of the shell. Decorticated specimens, probably belonging to the same species, occur in the *crossi* Bed, of Stoke Rochford, Lincolnshire.

M. barnackensis differs from *M. pontonensis* from the *Terebratula* Beds of Great Ponton and *Amberleya gemmata* Bed above the Weldon Beds by its smaller dimensions, shallower median sinus, more numerous finer and less prominent costae.

In the report of the Kettering Field Meeting in 1937 this species was recorded by L. Richardson (Richardson, L. and P. E. Kent, 1938, pp. 63, 65) as 'micromorphic rhynchonellid' from the upper bed of oolite sand near the top of the Weldon Beds of the Weldon Stone Quarries, Great Weldon and (p. 65) from a quarry S. of the bridge at King's Cliffe.

In the report of the Stamford Field Meeting it was recorded by Richardson (1939a, pp. 35, 36) as *Rhynchonella barnackensis* Muir-Wood MS. from the Barnack Rag of Wall's Quarry, Wansford and near Bonemills Quarry, Wittering, while in the Grantham report it was recorded (Richardson, L., 1939b, pp. 467, 471) from the Gastropod Beds of Great Ponton.

Hollingsworth and Taylor (1946a, p. 221, and 1946b, p. 244) list *Microrhynchia barnackensis* Muir-Wood MS. from the Upper Lincolnshire Limestone, Weldon Beds of Longhills Pit, 1 mile E. of Corby, Northamptonshire; and Taylor (1947, p. 251) mentions this species as a characteristic fossil from the Upper Lincolnshire Limestone.

***Microrhynchia pontonensis* sp. nov.**

Plate 5, figs. 1, 2 a, b, 3 a–c, 4 a–c

Diagnosis. *Microrhynchia* about 9 mm. long, 9 mm. wide and 7 mm. thick, differing from *M. barnackensis* in its larger dimensions,

more globose brachial valve, longer linguiform extension of pedicle valve and broader costae, about 16–18, not extending over posterior half of shell, 4–6 on fold and 5–7 in sinus.

Type-specimen. Holotype from the Upper Lincolnshire Limestone, *Terebratula* Beds of Great Ponton cutting near Grantham, Lincolnshire, Kent Colln. in the British Museum (Natural History) (BB.11280). Paratypes from Great Ponton, same Colln. (BB.11289); Longhills Pit, Weldon, Northamptonshire, Geol. Surv. Colln. (FD.477), and from 1400 yds. N. of Skillington Church, 6 miles SSW. of Grantham, Geol. Surv. Colln. (ZK.633).

Material and Locality.

About 20 specimens, usually imperfectly preserved, from the Upper Lincolnshire Limestone, Top Beds and Great Ponton *Terebratula* Beds from:

Rutland. Clipsham Stone, Old Quarry, Clipsham.

Lincolnshire. Near Skillington church, 1000 yds. NE. of Herrings Farm, 6 miles SSW. of Grantham; Braceby, west pit, about 6 miles E. of Grantham, near Ropsley; Haydor Quarry; Bullywells Quarry, South Rauceby; *Amberleya gemmata* Bed, quarry on east side of railway near Great Ponton station about 3 miles SSW. of Grantham; and *Terebratula* Beds, Great Ponton.

Dimensions. Holotype; maximum length 9.5 mm., maximum width 9.2 mm., maximum thickness 6.9 mm. Paratype (BB.11289), length 9.1 mm., width 9.5 mm., thickness 7.6 mm.

Description. (a) *External Characters.* In early growth-stages both valves are smooth and the shell is biconvex. The brachial valve then increases considerably in convexity, usually becoming globose, while the pedicle valve tends to flatten medianly and later develops a shallow median sinus. The median fold in the brachial valve is never elevated prominently above the lateral slopes and is only distinguishable in the gerontic stage. The umbo is short and rather massive and usually suberect. The deltidial plates are probably conjunct but are usually not preserved. The linguiform extension of the pedicle valve is long and tapering, while the lateral commissure is deflected towards the pedicle valve at a low angle to the vertical and then is sharply recurved.

The ornament is variably developed, but the costae are not as a rule developed on the posterior half of the shell and the shell appears smoother than in *M. barnackensis*. The costae are simple and rounded, separated by narrow sulci. On an average there are 16–18 on each valve with four or more on the median fold. The shell is thickened along the anterior and lateral commissures with close packing of the growth-lines.

(b) *Internal Characters*. Owing to the imperfect state of preservation of most of the specimens these could not be investigated.

Remarks. *Microrhynchia pontonensis* is almost invariably preserved in a tough oolitic limestone and specimens usually consist of detached valves. As in *M. barnackensis* the ornament is rather variable but, as a rule, the costae do not extend over the posterior half of each valve.

The median fold and sinus are always better developed than in *M. barnackensis* and the dimensions of the shell are usually about one-and-a-third times that of the Barnack Rag species.

Family TEREBRATULIDAE

Genus: **WELDONITHYRIS** gen. nov.

Diagnosis. Epithyrid, beak ridges indistinct, umbo often incurved in adult, foramen circular, marginate or labiate, sometimes in contact with brachial valve, concealing symphytium. Valves biconvex, brachial valve without posterior sulcus, but less convex than pedicle valve, elongate-oval in outline with short uniplicate stage immediately followed by sulcification. Growth-halts often conspicuous, growth-lines forming well-marked concentric ornament especially anteriorly. Loop extending for about one-third of length of brachial valve. Muscle-scars ill-defined and obscure. Median septum thread-like. Adductors diverging from umbo at angle of about 20° , increasing slightly in width anteriorly and extending less than half length of shell. Cardinal process small, narrow postero-anteriorly and posteriorly concave.

Genotype. *Weldonithyris weldonensis* sp. nov.

Species. *W. weldonensis* sp. nov. (p. 131), *W. elongata* sp. nov. (p. 135) and *W. pontonensis* sp. nov. (p. 134).

Range. Inferior Oolite, Upper Lincolnshire Limestone of Northamptonshire and Lincolnshire. Not at present recognised elsewhere.

Remarks. *Weldonithyris* differs from *Rugithyris* S. S. Buckman in internal characters, as shown by comparison of transverse sections of *W. weldonensis* and *Rugithyris submalogaster* (S. S. Buckman) (the type-species) from the Upper Inferior Oolite of Bradford Abbas and Broad Windsor, Dorset.

In *Rugithyris*, to which genus the species *W. weldonensis* sp. nov. was at first assigned, appearing in the field excursion reports as such, the growth lamellae are more ragged and the two valves less convex. The umbo in *R. submalogaster* is more produced than in *W. weldonensis* and projects over the brachial valve without concealing the symphytium, and the brachial valve is posteriorly sulcate. Buckman (1918, p. 127), in his diagnosis of *Rugithyris*, states that it is

'ligate to plano-convex to broadly uniplicate to sulcificate'. No ligate stage was observed in *Weldonithyris weldonensis* and the uniplicate stage is very short in this species, though better developed in *W. elongata* and *W. pontonensis*.

Weldonithyris also differs in internal structure from *Terebratula cortonensis* S. S. Buckman. This species from the Inferior Oolite, *concava-discites* Subzones of Corton Denham, near Sherborne, Dorset, resembles early growth stages of *W. weldonensis*. *T. cortonensis* has convexly curved hinge-plates comparable to those seen in transverse sections of *Lobothyris punctata* (Sowerby), the genotype of *Lobothyris* to which genus *T. cortonensis* is now assigned.

Weldonithyris weldonensis sp. nov.

Plate 6, figs. 4 a, b, 5 a, b, 6 a-c, 7 a-c, 8, 9, 10 a-c; Text-figs. 4, 5

Diagnosis. *Weldonithyris* with normally developed adult shells about 30 mm. long, 25 mm. wide and 18 mm. thick, subpentagonal to elongate-oval in outline, unequally biconvex, median fold ill-defined, incipiently episulcate, uniplicate stage scarcely developed, pedicle valve medianly flattened anteriorly. Umbo massive, incurved, usually concealing symphytium, foramen marginate to labiate, epithyrid, beak-ridges impersistent. Transverse growth-lamellae prominent, imbricating. Apical angle about 90°.

Type-specimen. Holotype from Upper Lincolnshire Limestone, Weldon Beds of Weldon Stone Quarry, preserved in the Sedgwick Museum, Cambridge (J.34, 866). Paratypes from same locality in same museum; and from same horizon of Weldon Grange Quarry (BB.6652, BB.11298); and from Longhills Quarry, Weldon (BB.9161). Micromorphs from Barnack Rag, Pipewell Quarry, Northamptonshire (BB.11277); and from Weldon Grange Quarry (BB.11297).

Material and Locality.

Numerous, usually imperfect, specimens from the Upper Lincolnshire Limestone, Weldon Beds.

Northamptonshire. Weldon Grange Quarry, S. of Great Weldon; Weldon Stone Quarry; Longhills Pit, E. of Corby; Walls Quarry, near W. end of Wansford tunnel (just in Huntingdonshire).

Micromorphs from Barnack Rag of Peterborough (Sharp Colln.); Longhills Pit, Weldon; Pipewell Quarry; near Bone-mills Quarry, Wittering.

Lincolnshire. Quarry 3/8 mile W. of Church, Sapperton; Stamford (Sharp Colln.).

Dimensions. Holotype; maximum length 31.4 mm., maximum width 23.7 mm., maximum thickness 16.4 mm. Paratype (BB.9161); maximum length 31.5 mm., maximum width 29 mm., maximum thickness 17.1 mm.

Dimensions of largest complete specimen examined (Geol. Surv. Colln. FD.481) (not figured); maximum length 38.8 mm., maximum width 34.6 mm., maximum thickness 21.9 mm. A fragment of a still larger specimen is estimated to have been 44 mm. wide (Geol. Surv. Colln. FD.438), while a detached pedicle valve in the Sedgwick Museum (J.34, 867), from Weldon, is 39.7 mm. long and 34.2 mm. wide.¹

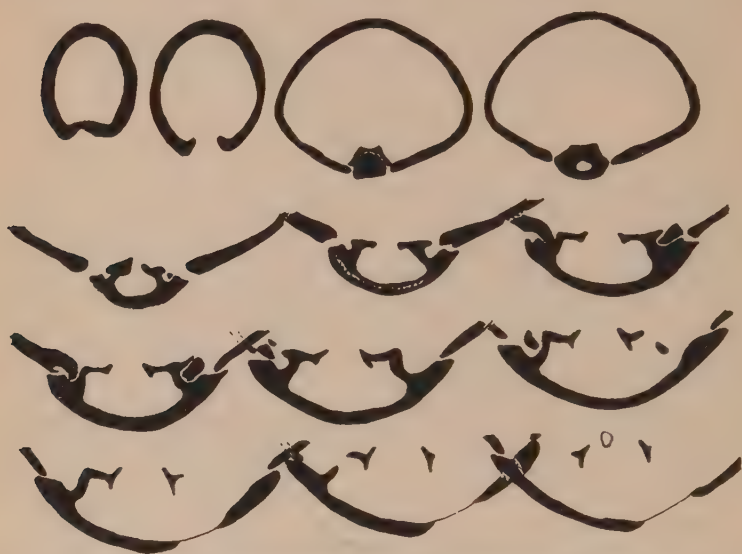


FIG. 4.—*Weldonithyris weldonensis* sp. nov. Upper Inferior Oolite, Upper Lincolnshire Limestone, Weldon, Northamptonshire. Geol. Surv. (FD.481). A series of 13 transverse sections through the posterior part of the shell. The low cardinal process is seen in sections 3 and 4. Sections approximately at 0.2 mm. apart. Sections 1 and 2, $\times 1\frac{1}{2}$. 3 and 4, nat. size, sections 5–13, $\times 2$. Only part of the pedicle valve is shown in sections 5–13.

Description. (a) *External Characters.* The brachial valve is convex in early growth-stages, circular then tapering forward and becoming subpentagonal or elongate-oval in outline. No uniplicate stage is developed but a slight median flattening, or sulcation of the shell, is accompanied by the development of two low diverging plications bounded laterally by a very shallow sulcus. The shell is marginally episulcate, but the biplication is never pronounced and the type of folding is very distinct from that normally developed in Inferior Oolite species. The pedicle valve is usually more convex than the

¹ A detached brachial and a pedicle valve from Weldon in the Geological Survey Colln. (FD.620, 621), which differed from *W. weldonensis* in not being anteriorly sulcinate or episulcate, and also in the more erect and produced umbo, attained even greater length—pedicle valve, length 46 mm., width 41.5 mm., brachial valve, length 44 mm., width 41 mm.

brachial valve, circular to subpentagonal in outline with no median sinus. Two shallow furrows, developed anteriorly, correspond to the low folds in the brachial valve.

The umbo in mature specimens is massive and incurved, usually in contact with the brachial valve. The foramen is circular and marginate in early growth-stages and becomes elongate and labiate in the gerontic stage, and sometimes telate. The symphytium is narrow and usually not exposed. The epithyrid beak-ridges are sometimes well-defined for a short distance and diverge from the hinge-margin. They are then faintly traceable as curving towards the hinge. The growth lines are numerous, often forming prominent lamellae.

(b) *Internal Characters*. As for genus.

Remarks. *W. weldonensis* differs from *Weldonithyris elongata* sp. nov. and *W. pontonensis* sp. nov. from the Upper Lincolnshire Limestone, *Terebratula* Beds of Great Ponton, by the episulcation of the anterior commissure, more incurved umbo concealing symphytium, labiate foramen, more circular or subpentagonal shell outline.



FIG. 5.—*Weldonithyris weldonensis* sp. nov. (Horizon and locality as for Fig. 4). Geol. Surv. (FD.442). Last of a series of 17 transverse sections showing the transverse band of loop projecting into the cavity of the valve. $\times 2$.

Specimens of *Weldonithyris* from the Weldon Beds show a fair amount of variation but the specimens are so fragmentary, the valves often detached and frequently crushed that no purpose would be served in describing additional species or subspecies from these beds. One of the commoner varieties in the Weldon Beds is a more circular form with considerably flatter brachial valve (Plate 6, figs. 5a, b, 7 a-c).

Conditions were evidently unfavourable for the development of brachiopods when the Weldon Beds were laid down because many of the specimens are asymmetrically developed, not as a result of crushing; others show extreme convexity of the valves in early growth-stages. Marked growth-halts are seen in many of the specimens; dwarfing and abnormal development of adult beak characters, such as incurvature of the umbo and a labiate and telate foramen,

are common. These dwarfed forms tend to be elongate-oval in outline with prominent growth-lamellae but rarely show anterior folding of the shell though the anterior commissure may be dorsally waved.

The Weldon Beds appear to have been partly dead-shell banks. Specimens with two valves attached are comparatively rare and the single valves (usually the more solid pedicle valve) are often found one inside the other. Sorting by current action also occurred as indicated by the Barnack Rag, where specimens of small size are mainly immature, but others, showing adult beak characters and anterior shell thickening without increase in size, are heaped together in great profusion together with minute gastropods, small limestone pellets and solid shell-fragments.

In the Weldon district, the Barnack Rag development of the Weldon Beds contains more broken shell-fragments and rolled limestone pebbles and fewer specimens of *Microrhynchia barnackensis* and micromorphic *W. weldonensis*.

***Weldonithyris pontonensis* sp. nov.**

Plate 6, figs. 2 a-c

Diagnosis. *Weldonithyris* about 31 mm. long, 26 mm. wide and 16 mm. thick, differing from *W. weldonensis* in its more erect umbo, smaller marginate instead of labiate foramen, well-exposed symphytium and in its normally uniplicate or incipiently sulcificate anterior commissure and by the short tapering linguiform extension which is anteriorly truncated. Apical angle 95° .

Type-specimen. Holotype from the Upper Lincolnshire Limestone, *Terebratula* Beds, quarry S. of Great Ponton Station, Lincolnshire—preserved in the Geological Survey Colln., London (ZK.607). Paratypes from the same horizon of Great Ponton preserved in the British Museum (Natural History) (BB.11299, BB.11278).

Material and Horizon.

Numerous specimens, often imperfectly preserved, from the above horizon near Great Ponton, Lincolnshire.

Dimensions. Holotype; maximum length 31.4 mm., maximum width 26.4 mm., maximum thickness 16.5 mm. Paratype (BB.11299); length 27 mm., width 24.5 mm., thickness 14.2 mm. Paratype (BB.11278); length 31.4 mm., width 27.5 mm., thickness 17 mm.

Description. (a) *External Characters.* In early growth-stages the shell is circular and biconvex with no sulcation of the umbonal region of the brachial valve. Uniplication in the holotype is developed about 24 mm. anterior to the brachial umbo but the median fold is always low and is usually distinguishable only near the anterior margin. The uniplica rarely becomes sulcificate and is never episulcate as in *W. weldonensis*. The lateral commissure is slightly deflected

towards the pedicle valve and recurved towards the brachial valve only at the anterior margin.

The beak-ridges are ill-defined and epithyrid. The foramen is rather small, slightly marginate and sometimes incomplete anteriorly, suggesting incipient labiation. The symphytium is narrow and well-exposed by the sub-erect umbo. The pedicle valve is less pinched in the umbonal region than in *W. weldonensis*.

Concentric growth-lines are well marked and concentric lamellae may be developed in the later growth-stages. Concentric colour-banding is seen in some specimens. Faint capillation occurs on the lateral slopes and on the anterior part of the shell.

(b) *Internal Characters*. Similar to those of *W. weldonensis*.

Remarks. *W. pontonensis* and *W. elongata* occur together in the *Terebratula* Beds at Great Ponton. These beds overlie the Ponton Gastropod Beds. The latter contain *Microrhynchia barnackensis* and are the equivalent of the Weldon Beds of Northamptonshire. Although *W. pontonensis* and *W. elongata* occur at a higher horizon than *W. weldonensis* the folding of the shell in these two species is less advanced than in *W. weldonensis*.

Many of these specimens from the *Terebratula* Beds are imperfectly developed and distorted through living in an unfavourable environment, probably the incoming of estuarine or brackish water conditions.

***Weldonithyris elongata* sp. nov.**

Plate 6, figs. 1, 3 a-c

Diagnosis. *Weldonithyris* about 25 mm. (up to 34 mm.) long, 19 mm. (up to 22 mm.) wide and 15 mm. (up to 18 mm.) thick, differing from *W. weldonensis* in its narrower, more elongate shell-outline, uniplicate, or incipiently sulcificate, instead of episulcate anterior commissure, less incurved umbo and more numerous and more prominent growth lines; and from *W. pontonensis* by its considerably narrower shell and slightly more convex valves, larger foramen often concealing symphytium. Apical angle 70°.

Type-specimen. Holotype from the Upper Lincolnshire Limestone, *Terebratula* Beds, Great Ponton, S. of Grantham, Lincolnshire, S. Sharp Colln., British Museum (Natural History) (B.16281). Paratype from the same horizon and locality, Richardson Colln., British Museum (Natural History) (BB.5895).

Material and Locality.

Numerous, often imperfectly preserved specimens, from the Inferior Oolite, Upper Lincolnshire Limestone, *Terebratula* Beds of Great Ponton, Lincolnshire; also from knoll in Lincolnshire Limestone, 1000 yds. NE. of Herrings Farm on parish boundary, 1400 yds. N. of Skillington.

Dimensions. Holotype; maximum length 34 mm., maximum width 22.1 mm., maximum thickness 18.2 mm. Paratype (BB.5895); length 25 mm., width 19 mm., thickness 14.8 mm.

Description. (a) *External Characters.* In early growth-stages, up to a distance of about 11 mm. from the umbo, the shell is circular in outline and the valves biconvex. The shell then tends to elongate, the pedicle valve increasing in convexity, while the brachial valve remains only slightly convex. Growth-lines are closely placed and well-defined, while prominent growth-lamellae in later growth-stages indicate growth-halts. Very fine longitudinal capillation is developed near the anterior margin in each valve and on the lateral slopes. In the holotype uniplication is first developed at a distance of 29 mm. from the umbo but the uniplica is only demarcated from the lateral slopes near the anterior margin and never forms a prominent median fold. Sulcification is not developed in the holotype. The lateral commissure is almost vertical and is deflected towards the brachial valve at the anterior margin. The umbo is imperfect in the holotype but is usually suberect exposing the short symphytium. The foramen is circular, marginate to just labiate, and the beak ridges are usually obscure.

(b) *Internal Characters.* Transverse sections show much the same structure as already described for *W. weldonensis*.

(b) SPECIES FROM THE UPPER ESTUARINE SERIES

Family LINGULIDAE

Genus: *LINGULA* Bruguière, 1797

Species: *Lingula kestevenensis* sp. nov.¹

Plate 5, figs. 16, 17

Diagnosis. *Lingula* about 15 mm. long, and 8 mm. wide, elongate-oval in outline, anterior margin subtruncate, lateral margins with slight convex curve, tapering gently to umbo and anterior margin. Growth-lamellae not conspicuous on venter, finely and irregularly longitudinally striated. Shell thin, sometimes concentrically banded.

Type-specimen. Holotype from the Upper Estuarine Series, Adamantine Clinker and Fireclay Works, Little Bytham, Lincolnshire, L. R. Cox Colln. (BB.11276). Paratypes from Portland Cement Co.'s Pit, Ketton, Rutland, Muir-Wood Colln. (BB.5127) and from same locality (BB.5131, 11300).

Material and Locality. About 20 fragmentary specimens in shelly band in clay or marly bed belonging to the Upper Estuarine Series below the Great Oolite White Limestone (see p. 114).

Rutland. Clipsham Old Quarry, 1 mile SE. of Clipsham Church, associated with *Burmishynchia*; Ketton Portland

¹ Name derived from Kesteven, one of the divisions or administrative counties of Lincolnshire.

Cement Co.'s Pit, Ketton; The Grange Quarry, 6/10 mile NNW. of Ketton Church; Messrs. Williamson and Cliff's brickworks, 1 mile SE. of Great Casterton Church, and $\frac{1}{2}$ mile NW. of Stamford Cemetery Chapel.

Northamptonshire. Priors Hall Ironstone Pit, SW. of church at Deene and 1 mile W. of Weldon Lodge, associated with *Burmihynchia*; trench 900 yds. SW. of church at Stanion and 1600 yds. W. by N. of Lower Lodge.

Lincolnshire. Adamantine Clinker and Fireclay works, Little Bytham, N. of Stamford; Thomson's Quarry, Ancaster.

Specimens are preserved in the British Museum (Natural History) and in the Geological Survey Collns., London.

Dimensions. Holotype; length 15.1 mm., width 7.8 mm., thickness of shell unknown as conjoined valves were not preserved. Paratype (BB.5127); length 14.8 mm., width 6.5 mm. Paratype (BB.11300); length 15.9 mm., width 8.3 mm.

Description. (a) *External Characters.* The dimensions just quoted appear to be of adult individuals and fragments of specimens of the same width occur fairly commonly. Immature individuals of small size also occur showing dark brown coloration posteriorly and light brown over the anterior two-thirds of the shell. The length of these small individuals is about twice the width. The shell is acuminate posteriorly, broadening and becoming almost parallel-sided and rounded-truncate anteriorly. Most of the adult shells show indication of concentric colour-banding of light and dark brown.

(b) *Internal Characters.* No complete internal cast was preserved. One incomplete internal cast of a brachial valve (BB.5129) showed two narrow slightly diverging ridges extending half the shell length, and traces of the transmedian and lateral muscle-scars.

Remarks. *L. kestevenensis* differs from *L. beani* Phillips from the Inferior Oolite, Dogger of Blea Wyke and Peak, Yorkshire, in its smaller dimensions, length 15 mm. and width 8 mm., as compared with 23 mm. and 12 mm., thinner shell, less truncate anterior margin, and less parallel lateral margins than the Yorkshire form. Concentric growth-lines are less prominent than in *L. beani*, and longitudinal striations are present in *L. kestevenensis*. The latter species is more robust and more rectangular in outline than *L. craneae* Dav. from the Oxford Clay or *L. ovalis* from the Kimmeridge Clay and Portland Sands.

No other species of *Lingula* appears to have been recorded from the Great Oolite Series of this country, though it is not uncommon in the Upper Jurassic.

The specimens of *L. kestevenensis* are associated with fragmentary *Burmihynchia* spp. and an assortment of lamellibranchs, whose white shells stand out in marked contrast to the chitinous valves of the *Lingula*. The specimens were evidently heaped together in dead

shell-beds, probably close to shore in the warm waters of a tidal estuary or gulf. Below the *Lingula* Bed at Ketton are plant beds with vertical plants, some with roots, yielding leaves and lycopod megaspores, which may indicate deltaic conditions. These spores have been described by N. Murray (1939, p. 478). Fragments of leaf cuticle of ginkgoalian leaves, as well as species of *Bennititales* and rare conifer cuticles, fern-spores and pollen-grains of *Caytoniales* also occur and are said to have been rotted before preservation and the upper and lower cuticles separated.

L. kestevenensis has been recorded by L. Richardson as a MS. name in the Stamford (1939a, incorrectly as *kestevensis*), Grantham (1939b) and Lincoln (1940) Field Meeting Reports, and by V. Wilson (1948).

4. LISTED SPECIES OF LINGULA FROM BRITISH JURASSIC

The following species of *Lingula* are at present known from the British Jurassic:

- Lingula davidsoni* Oppel. Lower Lias, Gloucestershire.
- Lingula anglica* Rollier (= *metensis* auctt.). Lower Lias, Gloucestershire.
- Lingula sacculus* ? Chapuis and Dewalque. Middle Lias.
- Lingula longo-viciensis* Terquem. Upper Lias, Yorkshire.
- Lingula beani* Phillips. Upper Lias, Yeovilian, *jurensis* Zone. Blea Wyke Beds, Yorkshire.
- Lingula kestevenensis* sp. n. Great Oolite Series, Upper Estuarine Series, *Lingula* Bed.
- Lingula craneae* Davidson. Oxford Clay, Christian Malford, Wiltshire.
- Lingula brodiei* Davidson. Coral Rag, Wheatley, Oxfordshire.
- Lingula* sp. Corallian, Ringstead Coral Bed, near Weymouth, Dorset.
- Lingula ovalis* J. Sowerby. Kimmeridge Clay.
- Lingula* cf. *ovalis* J. Sowerby. Portland Sand, Dorset.

EXPLANATION OF PLATES

All specimens are natural size unless otherwise stated. Specimens are preserved in the British Museum (Natural History), quoted as B.M.; Geological Survey Museum, London, quoted as Geol. Surv.; or Sedgwick Museum, Cambridge, quoted as Sedg. Mus. Registered numbers are in parentheses.

PLATE 5

- Fig. 1. *Microrhynchia pontonensis* sp. nov. Paratype. Upper Lincolnshire Limestone, 110 ft. above base of Limestone, 1000 yds. N. of Herring's Farm, and 1400 yds. N. of Skillington Church, 6 miles SSW. of Grantham, Lincolnshire. Geol. Surv. (ZK.633). Anterior view to show thickening along the anterior commissure (p. 128).

- Fig. 2. *Microrhynchia pontonensis* sp. nov. Paratype. Specimen crushed. Upper Lincolnshire Limestone, *Terebratula* Beds, Great Ponton near Grantham, Lincolnshire. B.M. (BB.11289). (a) Lateral view showing convexity of brachial valve. (b) Anterior view to show linguiform extension of pedicle valve. Both views $\times 1\frac{1}{2}$ (p. 128).
- „ 3. *Microrhynchia pontonensis* sp. nov. Paratype. Upper Lincolnshire Limestone. Longhills Pit, Weldon, Northamptonshire. Geol. Surv. (FD.477). (a) Anterior view to show linguiform extension. (b) Brachial valve view. (c) Lateral view to show convexity of brachial valve, and costae extending nearly to umbo. All views $\times 1\frac{1}{2}$ (p. 128).
- „ 4. *Microrhynchia pontonensis* sp. nov. Holotype. Specimen crushed. Upper Lincolnshire Limestone, *Terebratula* Beds. Great Ponton cutting, Lincolnshire. B.M. (BB.11280). (a) Brachial valve view. (b) Anterior view, commissure imperfectly preserved. (c) Lateral view. All views $\times 2$ approx. (p. 128).
- „ 5. *Microrhynchia barnackensis* sp. nov. Paratype. Upper Lincolnshire Limestone, Weldon Beds, Great Weldon, Northamptonshire. B.M. (B.97753). Longitudinal section to show one 'calcarifer' crus. $\times 3$ approx. (p. 125).
- „ 6. *Microrhynchia barnackensis* sp. nov. Holotype. Upper Lincolnshire Limestone, Barnack Rag, Bonemills Quarry, 9/10 mile W. 15° S. of church, Wittering, Northamptonshire. B.M. (BB.9718). (a) Brachial valve showing posteriorly smooth shell $\times 4$. (b) Anterior view showing short linguiform extension $\times 4$. (c) Lateral view $\times 4$. (d) Brachial valve view $\times 2$ (p. 125).
- „ 7. *Microrhynchia barnackensis* sp. nov. Paratype. Upper Lincolnshire Limestone. Upper part of Weldon Beds, Great Weldon Stone Quarry, Northamptonshire. B.M. (B.97752). (a) Lateral view, nat. size. (b) Brachial valve view $\times 4$. (c) Anterior view showing flat pedicle valve and slightly arched commissure $\times 3$ (p. 125; see also p. 126, Figs. 2 a-c).
- „ 8. *Microrhynchia barnackensis* sp. nov. Paratype. Upper Lincolnshire Limestone, Great Ponton Gastropod Beds, Great Ponton, Lincolnshire. Samuel Sharp Colln. B.M. (BB.11295). (a) Brachial valve view of typical weathered specimen. (b) Anterior view showing abnormally deep sinus and long tapering linguiform extension. Both views $\times 3$ (p. 125).
- „ 9. *Microrhynchia barnackensis* sp. nov. Broken specimen showing proximal part of crura. $\times 4$ approx. Upper Lincolnshire Limestone, Gastropod Beds, Great Ponton, Lincolnshire. Samuel Sharp Colln. B.M. (BB.11296) (p. 125).
- „ 10. *Acanthothiris crossi* (J. F. Walker). Lower Lincolnshire Limestone, *discites* Zone, *crossi* Bed, Stanton Limestone Quarries, South Witham, Lincolnshire. B.M. (BB.11272). (a) Lateral view showing two rows of spines. (b) Brachial valve view of typical weathered specimen showing the coarse costation and spine-bases. (c) Anterior view. All views $\times 3$ (p. 117).
- „ 11. *Acanthothiris broughensis* sp. nov. Holotype. Inferior Oolite, Cave Oolite, Brough, Yorkshire. J. F. Walker Colln. B.M. (BB.11294). (a, b) Lateral views showing greater convexity of brachial valve than in *A. crossi*, also fewer costae. $\times 2$ approx. (c) Brachial valve view showing fine costation and spine-bases. $\times 2\frac{1}{2}$ approx. (p. 127).
- „ 12. *Acanthothiris crossi* (J. F. Walker). Lectotype. Lower Lincolnshire Limestone, *discites* Zone, *crossi* Bed, Appleby Brigg, Lincolnshire. B.M. (B.31327). (a) Lateral view. (b) Anterior view. (c) Brachial valve view showing the coarse costation and spine-bases. All views $\times 3$ approx. (p. 117).

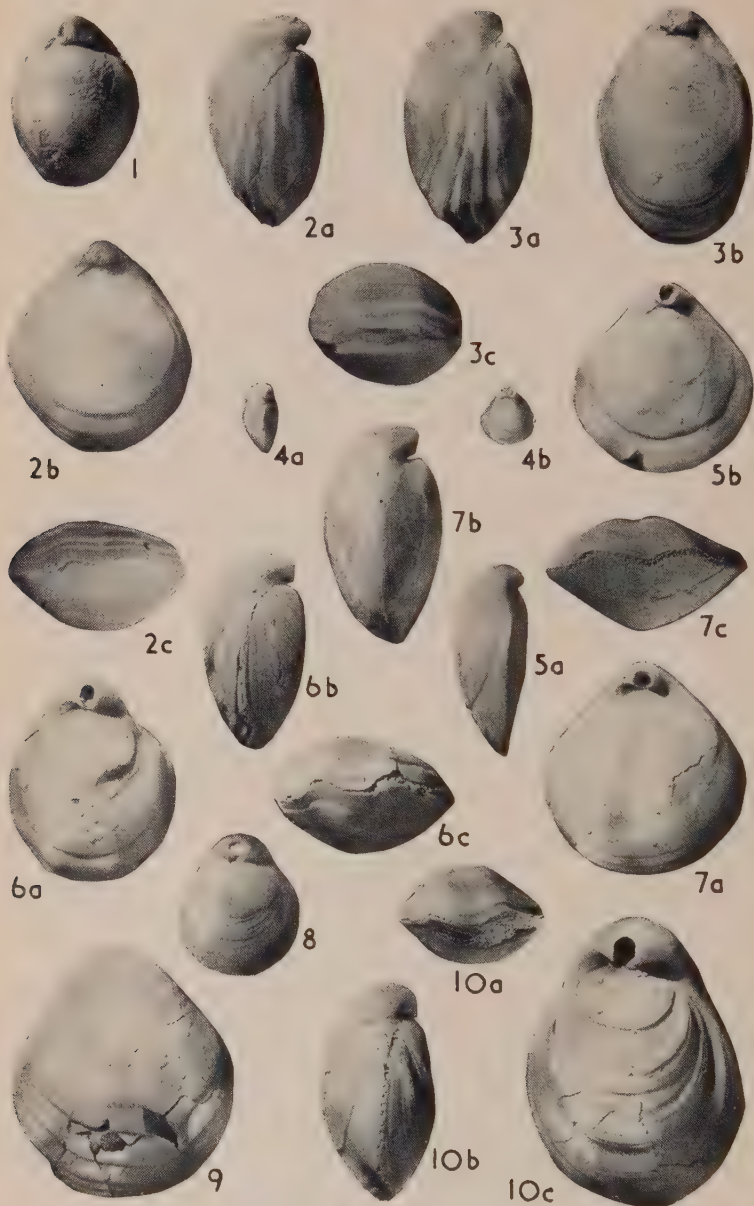
- Fig. 13. *Acanthothiris broughensis* sp. nov. Paratype. Inferior Oolite, Cave Oolite, Brough, Yorkshire. B.M. (B.19806). Pedicle valve showing costation and few spines (p. 123).
- , 14. *Acanthothiris broughensis* sp. nov. Paratype. Fragment of shell showing some spines attached. Horizon and locality as for Fig. 13. B.M. (B.19806) (p. 123).
- „ 15. *Acanthothiris broughensis* sp. nov. Part of pedicle valve $\times 3$ approx. Horizon and locality as for Fig. 13. B.M. (BB.11293) (p. 123).
- „ 16. *Lingula kestevenensis* sp. nov. Paratype. Great Oolite Series, Upper Estuarine Series, *Lingula*-Bed. Ketton Portland Cement Co.'s Pit, Ketton, Rutland. B.M. (BB.5127) (p. 136).
- „ 17. *Lingula kestevenensis* sp. nov. Holotype. Great Oolite Series, Upper Estuarine Series. Adamantine Clinker and Fire Clay Works, Little Bytham, N. of Stamford, Lincolnshire. B.M. (BB.11276) $\times 1\frac{1}{2}$ approx. (p. 136).

PLATE 6

- Fig. 1. *Weldonithyris elongata* sp. nov. Paratype. Inferior Oolite. Upper Lincolnshire Limestone, *Terebratula* Beds, Great Ponton, S. of Grantham, Lincolnshire. B.M. (BB.5895). Brachial valve view (p. 135).
- „ 2. *Weldonithyris pontonensis* sp. nov. Holotype. Upper Lincolnshire Limestone, *Terebratula* Beds, quarry S. of Great Ponton Station, Lincolnshire. Geol. Surv. (ZK.607). (a) Lateral view. (b) Brachial valve view. (c) Anterior view showing uniplicate commissure (p. 134).
- „ 3. *Weldonithyris elongata* sp. nov. Holotype. Upper Lincolnshire Limestone, *Terebratula* Beds, Great Ponton, S. of Grantham, Lincolnshire. Samuel Sharp Colln. B.M. (B.16281). (a) Lateral view showing almost vertical lateral commissure. (b) Brachial valve view. Apex of umbo not preserved. (c) Anterior view showing uniplicate commissure (p. 135).
- „ 4. *Weldonithyris weldonensis* sp. nov. Micromorph. Upper Lincolnshire Limestone, Barnack Rag, Pipewell Quarry, Northamptonshire. B.M. (BB.11277). (a) Lateral view. (b) Brachial valve view (p. 131).
- „ 5. *Weldonithyris weldonensis* sp. nov. Young specimen of broader, flatter variant. Upper Lincolnshire Limestone, Weldon Beds, Weldon Grange Quarry, S. of Great Weldon, Northamptonshire. B.M. (BB.11298). (a) Lateral view. (b) Brachial view (p. 131).
- „ 6. *Weldonithyris weldonensis* sp. nov. Holotype. Upper Lincolnshire Limestone, Weldon Beds, Weldon Stone Quarry, Weldon, Northamptonshire. Sedg. Mus. (J.34, 866). (a) Brachial valve view showing labiate foramen and the prominent growth-lines. (b) Lateral view. (c) Anterior view showing incipiently episulcate commissure (p. 131).
- „ 7. *Weldonithyris weldonensis* sp. nov. Paratype. Broad form. Upper Lincolnshire Limestone, Weldon Beds, Longhills Quarry, Weldon, Northamptonshire. B.M. (BB.9161). (a) Brachial valve view. (b) Lateral view. (c) Anterior view showing incipiently episulcate commissure (p. 131).
- „ 8. *Weldonithyris weldonensis* sp. nov. Micromorph. Upper Lincolnshire Limestone, Weldon Grange Quarry, Northamptonshire. B.M. (BB.11297). Brachial valve view $\times 2$ (p. 131).
- „ 9. *Weldonithyris weldonensis* sp. nov. Paratype. One of the largest pedicle valves examined. Upper Lincolnshire Limestone, Weldon Stone Quarry, Northamptonshire. Sedg. Mus. (J.34, 867) (p. 131).
- „ 10. *Weldonithyris weldonensis* sp. nov. Paratype. Upper Lincolnshire Limestone, Weldon Grange Quarry, Northamptonshire. B.M. (BB.6652). (a) Anterior view. (b) Lateral view. (c) Brachial view showing incurvature of umbo and telate foramen and the prominent growth-lamellae $\times 1\frac{1}{2}$ (p. 131).



JURASSIC BRACHIOPODS



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[To face p. 141.]

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A GEOLOGY OF SOUTH SHROPSHIRE

By W. F. Whittard, D.Sc., Ph.D., F.G.S.
(University of Bristol)

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SUMMARY.—The description of the geology of southern Shropshire aims at the incorporation of the results, including not a few as yet unpublished, which have been obtained during the last twenty-five years by a group of geologists, and does not seek to present the data against an historical background.

1. INTRODUCTION

MORE than a quarter of a century has elapsed since Watts directed the last, and the fourth, of the Association's long excursions to south Shropshire. The pamphlet, printed for those attending the 1925 excursion, was reissued in our PROCEEDINGS (Watts, W. W., 1925, pp. 321–63) and contains references for the years 1894–1925. A few of the publications which were printed before 1894 are also included by Watts, but a full list was thought to be unnecessary because, as he observed, a reasonably adequate bibliography appeared in the account of the 1894 excursion,¹ and a comprehensive list is also available for the period 1712–1887.² Accordingly, the references found on pp. 189–197 refer to those research results which have been printed since 1924.

Notwithstanding the fact that for more than a century and a half the geology of Shropshire has attracted many investigators, including some illustrious in geological science, there remain many problems to solve and the county still claims its ardent devotees. Mainly arising out of the inspiration and leadership of Watts and Cobbold, the last

¹ Lapworth, C. and W. W. Watts. 1894. The geology of South Shropshire, *Proc. Geol. Assoc.*, 13, 355.

² Whitaker, W. and W. W. Watts. 1889. List of works on the geology, mineralogy, and palaeontology of Shropshire. 1712–1887, *Trans. Shropshire Archaeol. Nat. Hist. Soc.*, 12, 33–62.

twenty-five years have witnessed the gleaning of much that was previously unknown; results have been published, much is in process of study and the present account of the geology of south Shropshire, which may be read alongside the admirably illustrated handbook entitled 'The Welsh Borderland' (Pocock, R. W. and T. H. Whitehead, 1935 and 1948), aims at the incorporation of this new information and offers some new interpretations.

For our immediate purposes, south Shropshire is assumed to comprise that area delimited by a line running eastwards from north of Shrewsbury to Wellington, thence almost due south along the Severn Valley to Bridgnorth, westwards to include Titterstone Clee, Ludlow and Leintwardine, north-westwards to Montgomery, northwards eventually to follow along the alluvial tract of the Severn and to enclose the Long Mountain and the Breidden Hills, and finally eastwards to return to Shrewsbury. Parts of the neighbouring counties of Herefordshire and Montgomeryshire are included, whereas the Forest of Wyre and the Bridgnorth district, which geologically belong to areas farther east, and the Clun Forest are excluded.

2. THE PRE-CAMBRIAN ROCKS

The Pre-Cambrian rocks fall fairly readily into three distinct categories; first, metamorphic, including the Rushton Schists and the Primrose Hill gneisses and schists; secondly, mainly volcanic or Uriconian, and, thirdly, mainly sedimentary or Longmyndian, but their relative ages have been, and still are, subjects for discussion. In the absence of fossils, the only field-data likely to establish the order of superposition include the evidence of contained fragments and of direction of dip, the latter being checked against fracture-cleavage, false-bedding, graded-bedding, erosion-channels and ripple-marking.

The Rushton Schists are foliated, feldspathic, quartz-mica schists in which garnets are not uncommon and epidote generally abundant. Their outcrop is limited by faults and unconformity, and good exposures are few. Farther to the south-west on Primrose Hill (Wrekin), gneisses and schists are associated with cataclastic and mylonitised acid igneous rocks, all being injected by veins of pink feldspathic material (Pocock, R. W., *et al.*, 1938, p. 23). Again, the relationships of these metamorphic rocks to the Uriconian are also probably indeterminable, because the area is isolated by faults and by the Cambrian unconformity. Confronted with these difficulties, geologists have been content to accept the metamorphic rocks of Rushton and of Primrose Hill as representing the most ancient of the Pre-Cambrian occurrences in Shropshire, but it is noteworthy the Geological Survey has suggested that the Rushton Schists have resulted from the metamorphism of gritty shales and flags (? Eastern Longmyndian) and the Primrose Hill gneisses and schists from tuffs and lavas (? Uriconian) (*loc. cit. supra*, pp. 24, 31).

The Uriconian is distributed in two lines of well-defined hills. The Eastern Uriconian is found in the north in the Lilleshall, Wrekin, Charlton Hill and associated outcrops, and these are connected by isolated masses with Lawley, Caer Caradoc, Helmeth, Hazler, Ragleth and Cardington which occur east of the Longmynd; the last appearance is farther to the south in the structurally complicated area of Wartle Knoll. Corresponding to this chain of hills is the linear series of inliers of the Western Uriconian developed on the west of the Longmynd; they commence with Pontesford Hill and nearby outcrops and may be followed in detached masses by Coldyeld and terminate near Linley close to the Silurian unconformity. The rock-types embrace lavas, such as devitrified, flow-banded, sometimes brecciated, spherulitic, pyromeroidal and perlitic rhyolites and less common basalts; bedded pyroclastic rocks, such as vitric, lithic, crystal and palagonite tuffs, which are often false-bedded; volcanic agglomerates and breccias. Intruded into this suite are pink granophyres, felsites and dolerites. Petrologically no distinction can be made between the rocks of the Eastern and Western Uriconian.

TABLE I. SUGGESTED SUCCESSION OF THE PRE-CAMBRIAN ROCKS

LONGMYNDIAN	Wentnor 'Series'	(h) Bridges Group: purple shales and mudstones with some arenaceous beds.
		(g) Bayston-Oakwood Group: purple grits and conglomerates with some shales and tuffs.
	PROBABLE UNCONFORMITY ¹	
	Stretton 'Series'	(f) Portway Group: purple and green shales with some thin flags and pebbly beds; Huckster Conglomerate at the base. ¹
		(e) Lightspout Group: grey and green flags and grits.
		(d) Synalds Group: purple shales with some green shales and flags: Cardingmill Grit at base and Batch Volcanic Group occupying stratigraphically higher position.
		(c) Burway Group: greyish-green shales and flags: Buckstone Rock at base.
		(b) Stretton Shales (Watling and Brockhurst Shales): greenish shales with small lenticles of cone-in-cone limestone.
		(a) Helmeth Grits: four tuffaceous beds interleaved with shales.

NO OBVIOUS UNCONFORMITY (? OVERLAP)

URICONIAN: east and west of the Longmynd

RELATIONSHIP UNKNOWN

Metamorphic rocks of Rushton and Primrose Hill

The Longmyndian is divided into an eastern or Stretton 'Series' and a western or Wentnor 'Series', and each is further subdivided into several groups (see Table I). In the Church Stretton area the Stretton 'Series' is inclined to the west at high angles, and the frac-

¹ The probable unconformity may occur at the base of the Huckster Conglomerate, and the Portway Group would then be better classified with the Wentnor 'Series' (p. 148).

ture-cleavage and false-bedding indicate that the beds, with rare exceptions, possess a normal succession and they are not inverted as some authorities have claimed. The Stretton 'Series' comprises grey, green and purple shales, flags and grits with some easily detected 'marker' beds such as the Helmeth Grits, the silicified tuff and shale termed the Buckstone Rock, the Cardingmill Grits and the andesitic tuffs of the Batch Volcanic Group. The coarse-grained rocks contain appreciable amounts of fragmental volcanic material. The Wentnor 'Series' exhibits a threefold division into two major groups of sandstones, arkoses, grits and conglomerates (the Bayston Group to the east and the Oakswood Group to the west) separated by the thick Bridges Group which is predominantly argillaceous but includes subordinate grits and sandstones. Traced northwards, the Wentnor 'Series' and the topmost beds of the Stretton 'Series' undergo a reversal in dip and thus at Haughmond Hill in the farthest north an easterly, instead of a westerly, dip prevails.

Whereas the Stretton and Wentnor 'Series' possess diagnostic features, the Eastern and Western Uriconian are so much alike that they can only be differentiated geographically.

The problem of the time-relationships of these four divisions has occupied geologists over a period in excess of sixty years and still an accepted solution is not in sight. The Eastern Uriconian rocks of Caer Caradoc, Helmeth, Hazler and Ragleth are succeeded in ascending stratigraphical order by the Helmeth Grits; these constitute a transitional series into the Stretton Shales, which naturally fall into the Stretton 'Series' of the Eastern Longmyndian. The Helmeth Grits make a subdivision about 100 ft. thick in which four massive beds of tuffaceous grits alternate with green, purple and brown shales identical with the Stretton Shales (Cobbold, E. S. and W. F. Whittard, 1935, p. 351). The tuffaceous grits contain angular fragments of devitrified, flow-banded, spherulitic and perlitic rhyolites, trachyandesites, and rare granitic and granophyric aggregates; the identity of these fragments with the Uriconian is indubitable. The four grits are better described as consolidated, mud-contaminated, lithic tuffs, of which the larger fragments have been derived by volcanic processes from already consolidated Uriconian lavas, and they may be considered as four minor volcanic episodes representing the dying efforts of the Uriconian activity. The Eastern Uriconian thus antedates the Helmeth Grits which are older than the Stretton Shales because they are gradational to them. But the Stretton Shales are overlain by other members of the Stretton 'Series' and there must be an upward westerly stratigraphical sequence because the inclination of the beds, the fracture-cleavage and the false-bedding combine to demonstrate the normal succession.

The Wentnor 'Series' is characterised by the development of three powerful conglomerates in the Bayston Group and three in the Oakswood Group, although the maximum number of conglomerates

is not always present in each Group. The Bayston Group maps as the eastern belt of the Wentnor 'Series' and its three conglomerates have been named from east to west after Haughmond, Darnford and Stanbatch. The contained pebbles are mainly formed of quartz and quartzite, but Uriconian volcanic rocks are represented and constitute 10–20 per cent of the pebbles in the Stanbatch Conglomerate, about 10 per cent in the Darnford Conglomerate and 80–90 per cent in the Haughmond Conglomerate. The three conglomerates in the Oakswood Group also yield pebbles derived from Uriconian outcrops. The easternmost or Lawn Hill Conglomerate carries 20 per cent of such pebbles, the middle or Oakswood Conglomerate is coarser-grained and analyses up to 50 per cent of volcanic rocks, and the Radlith Conglomerate provides quartz and quartzite pebbles contained in a matrix rich in small pieces of Uriconian material (Pocock, R. W., *et al.*, 1938, pp. 48, 55). Uriconian fragments thus constitute an important element in the various conglomerates of the Wentnor 'Series'; but from whence were they derived? Both Cantrill and Whitehead (*in* Pocock, R. W., 1938, pp. 11–12) contend that the size and frequency of the pebbles generally diminish to the east and some conglomerates merge into sandstones, implying a westerly source from outcrops of the Western Uriconian. The Wentnor 'Series' is thus claimed to be younger than the Western Uriconian, and, in the appended paper, James gives further confirmatory information (p. 198).

Allowing that the Eastern Uriconian antedates the Stretton 'Series' and the Western Uriconian antedates the Wentnor 'Series', what is the relationship between the Stretton and Wentnor 'Series', and are the Eastern and Western Uriconian rocks of about the same or of vastly different age?

Blake¹ maintained that the Wentnor 'Series' rests unconformably upon the Stretton 'Series', a relationship which neither Lapworth (see Watts, W. W., 1925a, p. 333) nor Callaway² could accept. Evidence supporting Blake's hypothesis is found in the greater geographical extension of the Wentnor 'Series', reaching from the Longmynd eastwards beyond the Stretton Hills and south as far as Old Radnor and Huntley in Gloucestershire, as compared with the restricted distribution of the Stretton 'Series', suggesting a widespread and violent overstep (Cobbold, E. S. and W. F. Whittard, 1935, p. 356). Furthermore, no Cambrian or Ordovician rocks are known to have contacts with the Stretton 'Series', but they are found in juxtaposition with the Wentnor 'Series'; accordingly, it may be argued that the Stretton 'Series' was not exposed to denudation and the most likely cover would be supplied by the Wentnor 'Series'. Whatever be the true explanation, the fact remains that no unconformity has been

¹ Blake, J. F. 1890. On the Monian and Basal Cambrian Rocks of Shropshire, *Quart. Journ. Geol. Soc. Lond.*, **46**, 386.

² Callaway, C. 1891. On the unconformities between the rock-systems underlying the Cambrian Quartzite in Shropshire, *Quart. Journ. Geol. Soc. Lond.*, **47**, 112.

satisfactorily detected in the field, but James, who is now mapping the southern portion of the Longmynd, finds that at several localities the Huckster Conglomerate behaves in a discordant manner; if a major unconformity exists on the Longmynd it may occur not at the base of the Bayston Group but below the Huckster Conglomerate of the Portway Group; the Portway Group would then be more conveniently classified as the basal member of the Wentnor 'Series', and not as the topmost division of the Stretton 'Series' (Table I).

The Eastern and Western Uriconian rocks are either of about the same age or are separated by a vast interval of time. Rock-types from both occurrences can be perfectly matched and such close identity would not be expected if they represented volcanic eruptions of very different ages; although on petrological reasoning this is not impossible, it is, nevertheless, improbable. Assuming consanguinity, the whole of the Uriconian is older than the Longmyndian, and if the Wentnor 'Series' is unconformable to the Stretton 'Series' then it is the youngest of the Pre-Cambrian divisions. The deduction, which is now permissible, assuming the above-mentioned tenets are valid, is that the Wentnor 'Series' must also be unconformable to the Uriconian rocks on the west side of the Longmynd. Volcanic rocks are found in small outcrops on the east of the main mass of Pontesford Hill; the Pontesford Brook (Lyd Hole) occurrence is placed in the Uriconian by Whitehead but he argues that the lavas in the Habberley Brook are of Lower Ordovician age (Pocock, R. W., *et al.*, 1938, pp. 34, 93). These latter lavas are flow-banded and devitrified, and although they may show slight differences in colour and in texture from the Uriconian, yet they resemble none of the Ordovician volcanic rocks, which are plentifully exposed in the extensive suites developed in the Ordovician inliers of the adjacent Shelve-Corndon country and of the Breiddens; whatever be the significance or causes of devitrification, in none of these Ordovician areas are there any devitrified rhyolites, and, in fact, lavas are rare and usually andesitic, whereas, in the Uriconian, they are common and usually rhyolitic. The presence of devitrified lavas in the Habberley Brook is of the greatest importance and I find myself unable to agree with Whitehead that the rocks are Ordovician in age; he states this rhyolite is 'further dissociated from the Lyd Hole rhyolite by the fact that the parts of the Longmyndian sequence with which the two rocks are respectively in contact are separated by about 1200 feet of strata', and this is the main reason for attributing an Ordovician age to the Habberley Brook rhyolite (Whitehead, T. H., 1929, p. 124). Whereas the Ordovician shales show sandy and pebbly deposits resting upon the irregular surface of the rhyolite with conglomerate lapping around protuberances, nowhere has the contact between the Wentnor 'Series' and the rhyolite been seen; thus the base of this rhyolite, instead of sloping under the Ordovician rocks as depicted by Whitehead (1929, fig. 2), may be inclined in the opposite direction under the

Longmyndian. The latter interpretation would permit the rhyolite being attributed to the Uriconian; in which case the Wentnor 'Series' is transgressive because, on Whitehead's maps, it is in contact with different divisions of the Uriconian (*in* Pocock, R. W., *et al.*, 1938, figs. 7, 14). Again, confirmatory evidence for an unconformity between the Uriconian and Wentnor 'Series' has been found by James who, working at the other end of the Pontesford-Linley outcrops where the dip is now westerly, has discovered, near Chittol Wood, that not only are the rocks here inverted but the inverted Uriconian rests upon different members of the adjacent Wentnor 'Series' (see p. 198).

The preceding discussion would seem to indicate that, excluding the metamorphic rocks of Rushton and Primrose Hill, the Uriconian is the oldest group of rocks and is succeeded, apparently in normal sequence, by the Stretton 'Series'; the Wentnor 'Series' is unconformable to both, its transgressive margins reaching down to the Uriconian on the west, finding contact with the Stretton 'Series' in the Longmynd, thence, by assumption, overstepping the Stretton 'Series' on to the Uriconian, extending eastwards beyond the Uriconian of the Caer Caradoc-Ragleth line of hills into the Cwms and on to Hope Bowdler Hill, and ranging far to the south into north-west Gloucestershire.

The succession of strata in the Wentnor 'Series' has hitherto been assumed to be normal, the Bayston Group on the east being separated from the Oakwood Group on the west by the intervening argillaceous belt of the Bridges Group. The rocks of the Bayston Group in the south and mid-Longmynd possess a westerly dip but, near Linley, the Oakwood Group is now known from James's mapping to be upside down, although the same westerly dip prevails (see p. 198). Thus in the south-western corner of the Longmynd, and for a few miles farther north, the sandstones, conglomerates and shales of the Oakwood Group are older, not younger, than the Bridges Group, and would thus be comparable in age with the Bayston Group as shown on Table I. Whitehead has analysed the frequency of different kinds of pebbles in the various conglomerates and has shown that no statistical similarity exists between corresponding conglomerates of the Bridges and Oakwood Groups; but, with rudaceous rocks, not only would the composition be expected to vary in individual conglomerates but there is no surety that the conglomerates exposed at the surface in the Bayston Group would be the same as those in the Oakwood Group, assuming the two groups to be approximately of the same age. Large-scale and deep synclinal overfolding is required to explain the repetition of the Bayston Group in the form of the Oakwood Group; in the south Longmynd, where westerly dips are universal and where Whitehead has also advanced other data suggesting inversion in the Bridges Group (Pocock, R. W., *et al.*, 1938, p. 13), the western limb of this

major synclinal fold would be inverted involving the Oakswood Group and part of the overlying Bridges Group. In the north Longmynd, on the other hand, the sequence is normal on the west around Pontesford, but near, and north of, Stapleton inversion would affect the Bayston Group. The change in curvature of the axial plane, or planes, of the major synclinal overfold, as traced from the south to the north, would not be great because, in whichever direction the Longmyndian rocks may be inclined, on the average the angles range from 60–90 degrees.

The arguments, which have been given, are known to be highly conjectural; the conclusions reached can obviously be criticised and can be said to raise more difficulties than they solve, but eventually this approach to the problem may lead to an acceptable solution.

The remarkable similarity of the Western and Eastern Uriconian has been used as an argument in favour of their contemporaneity, and, if this be permissible, then the approximate correlation of the Wentnor 'Series' with part of the Torridonian automatically follows. The Torridonian contains conglomerates in the Applecross Group and these, on the authority of Teall, include pebbles of felsite which are 'identical in all essential respects with the felsites belonging to the Uriconian series of Shropshire',¹ but no Uriconian rocks are found *in situ* in Scotland. If there are reasons for supposing that the Uriconian type of rock-assemblage is unlikely to have been repeated in geological time in Shropshire, there is no additional reason why it should be of a different age in Scotland. The Uriconian provided the waste from which part of the Torridonian was constructed, and can be assumed to be approximately contemporaneous with the Uriconian of Shropshire; since the Wentnor 'Series' and the Torridonian are similar in so many respects, it is reasonable to conclude that, as proposed by Lapworth,² they were laid down at about the same period of geological history.

3. THE CAMBRIAN SYSTEM

The most complete development of fossiliferous Lower Cambrian in Britain is found in the classical sections of south Shropshire, whence most of our information is due to the indefatigable researches of Cobbold (1927, p. 551). The Comley area, near Church Stretton, famous because it was here that Lapworth first identified a British occurrence of an olenellid trilobite and thus proved the Pre-Cambrian age of the Uriconian hills and of the Longmynd, is structurally complex and poorly exposed; Cobbold dug numerous excavations to establish the succession tabulated below (Table II), and a confirmatory sequence was later determined by the Geological Survey work-

¹ The geological structure of the North-west Highlands of Scotland. *Mem. Geol. Surv. Gt. Britain*, 1907, 283.

² Lapworth, C. and W. W. Watts. 1910. Shropshire. *Geol. Assoc. Jubilee Vol.*, 747.

ing in the vicinity of Rushton, not far from the Wrekin (Cobbold, E. S. and R. W. Pocock, 1934, p. 305; Pocock, R. W., *et al.*, 1938, p. 59).

TABLE II. SUCCESSION OF CAMBRIAN ROCKS

Upper Cambrian	{ Black <i>Ctenopyge-Eurycare</i> Shale (circa 13 ft.) POSSIBLE FAUNAL BREAK Grey <i>Orusia lenticularis</i> Shale (circa 63 ft.) POSSIBLE FAUNAL BREAK
Middle Cambrian [†]	{ <i>Agnostus laevigatus</i> Horizon (?) <i>P. forchhammeri</i> Shales and Grits <i>P. davidis</i> Flags Shales surmounted by <i>P. rugulosus</i> Grit Comley Breccia-Bed (<i>P. intermedius</i>) <i>P. hicksi</i> -fauna <i>P. bohemicus salopiensis</i> -fauna (loose limestone blocks) <i>P. groomi</i> Grits, Conglomerates, Breccias
	UNCONFORMITY
Lower Cambrian	{ Comley Limestone (6 ft.) Comley Sandstone (circa 500 ft.) Quartzite (variable thickness up to 140 ft.)
	{ <i>Lapworthella</i> Limestone (6 in.) <i>Protolenus</i> Limestone (6 in.) <i>Strenuella</i> Limestone (9 in.) <i>Eodiscus</i> Limestone (1 ft. 9 in.) <i>Callavia</i> Beds (2 ft. 6 in.) <i>Aluta-Indianites</i> Beds ' <i>Holmia</i> ' Horizon <i>Acrothele prima</i> Shale <i>Obolella groomi</i> Horizon
	UNCONFORMITY
Pre-Cambrian	Rushton Schists, or Uriconian, or Wentnor 'Series'

The basal quartzite reposes with strong unconformity upon either Uriconian or Wentnor 'Series'; usually glauconite is present in small amounts, and occasionally breccias and conglomerates occur near the base of the subdivision.

The passage-beds between the Quartzite and richly glauconitic Comley Sandstone, comprise alternations of quartzite, conglomerate and shale, and have provided the earliest undisputed fossils, such as *Obolella groomi* and *Hyalolithus strettonensis*. The *Acrothele prima* Shale of Rushton yields hyolithids, Conchostraca and horny brachiopods while, at Comley, conchostracan genera, such as *Aluta*, *Indianites* and *Beyrichona*, are recorded from green sandstones overlying the 'Holmia' Horizon (Cobbold, E. S., 1936, p. 230); the latter is the position of *Kjerulfia? lundgreni*, known by a solitary specimen collected near Robin's Tump.

The Comley Limestones, aggregating a thickness of six feet, are remarkable in recording five distinct faunas. The *Callavia* Beds are

[†] Thicknesses of the subdivisions cannot reliably be given.

green glauconitic sandstones at the base and pass upwards into the well-known red and purplish limestones; the most significant fossils here are the olenellid trilobites, of which *Callavia*, represented by three species, is the commonest genus, but Raw (1936, p. 238) also lists *Holmia?* sp. nov., *Kjerulfia?* *granulata*, *Nevadia cartlandi* and *Wanneria?* *pennapyga*. The succeeding limestones are variously coloured and sometimes contain pebbles of quartz; phosphate appears in the *Callavia* Beds, increases in importance in higher limestones and culminates in the *Lapworthella* Limestone. *Callavia* persists into the *Eodiscus* Limestone as *C. cobboldi*, but is there accompanied by *Protolenus pustulatus* (referred to *Strenuella* by Lake in 1932 (1906-46, p. 169)). The faunas of the *Protolenus* and *Strenuella* Limestones are distinct from those below, and from one another, while the overlying *Lapworthella* Limestone contains no recognisable trilobite.

Groom's discovery of *Paradoxides* at Comley, shortly after Lapworth had detected the olenellids, proved the existence of Middle Cambrian deposits, but their stratigraphical and palaeontological relations with the Lower Cambrian remained undetermined until Cobbold devoted his patient attention to the area. An unconformity was detected, but the unravelling of the stratigraphical tangle did not proceed unchecked, because anomalous faunas were obtained from conglomerates and breccias at Robin's Tump, Dairy Hill and elsewhere.

At Robin's Tump, a conglomerate rests unconformably upon a glauconitic sandstone, but the field-relationships were obscure; a trench exposed a dark limestone interbedded in the glauconitic sandstone and, where the dip carried the limestone as a rib of rock near to the unconformity, a surface of erosion was found. The rib exhibited a pocket and clefts enlarged by solution and filled with fragments of fossiliferous Lower Cambrian limestone; these were set in a glauconitic sandy matrix, which provided indigenous specimens of *Paradoxides* and *Kootenia*,¹ later recognised as belonging to the *P. groomi* Horizon. The limestone fragments had thus been produced by the breakdown of Lower Cambrian rocks, which had been compacted and folded before the unconformable deposition of Middle Cambrian sediments commenced.

Whereas at Robin's Tump the distinction between matrix and derived fragments is obvious, it is otherwise at Dairy Hill where a *Protolenus-Callavia* assemblage was associated with *Paradoxides*. These mixed faunas 'might have been held to prove that *Paradoxides* and *Olenellus* were, in part at least, contemporaneous, in which case the breccia-bed would have been regarded as a passage-bed, where the two faunas overlapped'.² Fortunately, the breccia-bed was not

¹ *Dorypyge lakei* from Robin's Tump and *D. reticulata* from the Breccia-Bed have been placed by Resser in *Kootenia* (1942, 27).

² Cobbold, E. S. 1913. The trilobite fauna of the Comley Breccia-Bed (Shropshire), *Quart. Journ. Geol. Soc. Lond.*, 69, 41.

unearthed until the Middle and Lower Cambrian assemblages had been elucidated. The Comley Breccia-Bed, like the conglomerate at Robin's Tump, contains derived fossiliferous Lower Cambrian limestone, but the indigenous fauna is younger and appertains to the *P. intermedius* Horizon. The Middle Cambrian conglomerate and the breccia-bed, being of different ages, demonstrate that the folded Lower Cambrian strata, with which they make unconformable contacts, must have been subjected to extensive erosion at two different periods at least, and accentuate the importance of the stratigraphical break.

At Comley, between the *P. groomi* Grits and Conglomerates and the Comley Breccia-Bed, there are a few hundred feet of shales and grits of which the correlation is not apparent; at Rushton, however, some loose blocks of limestone yielded fossils new to Shropshire and, since these bear some relation to the *Ctenocephalus exsulans*-fauna at the base of the *P. tessini* Zone of Scandinavia, their stratigraphical position is adjudged to be above the *P. groomi*-fauna and below the *P. hicksi*-fauna; the latter has only been found at one locality in Cherme's Dingle, near the south-west end of the Wrekin.

Continuing the succession above the Comley Breccia-Bed, a few hundred feet of unproductive shales are capped by thin arenaceous beds characterised by *P. rugulosus*; the succeeding 14 ft. of flaggy beds contain the well-known assemblage of which *P. davidis* is the index-fossil. At Comley, the highest Middle Cambrian horizon yields brachiopods indicative of the *P. forchhammeri* Zone of Scandinavia but, near Rushton, trilobites have, in addition, been recovered from calcareous bituminous grits (Cobbold, E. S. and R. W. Pocock, 1934, p. 393). Furthermore, in the same stream-section at Rushton, some soft shales, interleaved with coarse grits, succeed the *forchhammeri* Beds and although the fauna is sparse it is believed to show the presence of the topmost Middle Cambrian, or *Agnostus laevigatus* Zone of Scandinavia.

The Upper Cambrian is poorly represented in Shropshire and evidence for no more than two of the six zones of Scandinavia has been gained. The grey *Orusia lenticularis* shales are recorded from Comley; at the Bentleyford Brook, Stubblefield (1930, p. 55) has not only listed a larger fauna from those beds, including *Beltella* cf. *bucephala* and *Parabolinella* aff. *williamsoni*, but has announced the existence in black shales of the *Ctenopyge flagellifera* Subzone of Sweden. Later, Cobbold and Pocock (1934, p. 391) listed a fauna of about the same age collected from loose blocks of bituminous limestone found in the Dryton Brook, nearly two miles south-west of Rushton. The Bentleyford section traversed strata contained between the Middle Cambrian and Tremadocian; the zonal correlation of the Upper Cambrian in this section implies a faunal break between the *Orusia* Beds and the *Ctenopyge* Beds, and

also a more important gap between the *Ctenopyge* Beds and the Tremadocian, that is assuming the shales do not represent a greatly condensed sequence.

Other areas of Cambrian rocks are known to exist in Shropshire. At Lilleshall, Comley Sandstone is assumed to be faulted against the Uriconian (Whitehead, T. H., *et al.*, 1928, p. 15) and in a borehole, put down from the bottom of the Cruckmeole Shaft of Hanwood Colliery, a glauconitic sandstone, presumably Comley Sandstone, was penetrated (Pocock, R. W., *et al.*, 1938, p. 131). At the Sharpstones and Hillend, near Cardington, Cambrian Quartzite and Comley Sandstone are exposed, but an extensive programme of trench-digging is here required before details of the Cambrian succession can be made available; of promise are the maroon and calcareous sandstones which have been seen in one small outcrop.

4. THE ORDOVICIAN SYSTEM

(a) **The Tremadocian Series.** Arguments advanced to support the demarcation of Systems or of Series at this or at that level are only too prone to become contentious, but, with regard to the Tremadocian, the well-tried method of delineation by unconformity clearly should not be applied because it is contradictory when successions in Britain and Scandinavia are compared. In Britain, the Tremadocian is traditionally included as the topmost member of the Cambrian because an upper limit is defined in the field by an unconformity and by a lithological break; there is no direct evidence in the type-area in North Wales of a discordant relationship between the Tremadocian and the underlying Dolgelley Beds of the Upper Cambrian but there is, at least, a lithological change; significantly, a faunal break probably exists between the Dolgelley Beds and Tremadocian in the Bentleyford section (Stubblefield, C. J., 1930, p. 62). Elsewhere, as in Scandinavia and on the Continent, the Tremadocian is classified with the Ordovician; in Scandinavia, where in several localities an unconformity is found, it determines the lower, and not the upper, limit of the Series and there is usually an upward gradation into the Arenigian. These two conflicting facts should be brought into harmony, although some authorities would reasonably argue that the definition of Systems is at the best founded upon arbitrary methods, and the most acceptable usage is that which is of the greatest convenience. Furthermore, from the point of view of distribution the Tremadocian in Britain appears to conform more with the Cambrian than with the rocks normally accepted as Ordovician.

Turning to the palaeontological evidence—and in practice fossils are largely employed in the definition of stratal boundaries—the greater part of the Tremadocian fauna has affinities more with the

Ordovician than with the Cambrian. The first 'graptoloids'¹ are recorded from the Tremadocian where they are associated with the Trinucleidae (*Orometopus*), Asaphidae (*Asaphellus*, *Niobe*, *Niobina*, *Borthaspis*²), Nileidae (*Symphysurus*, *Platypeltis*), Cyclopygidae (*Cyclopyge*) and Cheiruridae (*Anacheirus*), all of which are dominantly Ordovician families of trilobites; furthermore, with regard to the typical genus *Shumardia*, the only other records are from the Ordovician, while the rare *Apatokephalus* and *Macropyge* are considered by Lake to be nearly allied to the Ordovician *Robergia* (1931, p. 124). The Cambrian aspect of the fauna is shown by the Agnostida, Olenidae (*Leptoplastus*, *Beltella*, *Angelina*) and the Triarthridae (*Parabolinella*, *Peltura*, *Triarthrus*) but these three trilobite-groups all drag on through the Ordovician into the Bala. The age-affinity of *Dikelocephalina* and *Euloma* are inconclusive. When these faunal indications are balanced against one another, the scales are heavily weighted in favour of the inclusion of the Tremadocian in the Ordovician.

The Tremadocian shows its fullest expression in the Wrekin outcrop, which reaches south-westwards to Evenwood, where Stubblefield and Bulman (1927, p. 105) have established a succession, given below, which can be directly correlated in most of its subdivisions with zones determined in Sweden and Norway (*op. cit.*, correlation table facing p. 118).

Arenig, Caradoc, Valentian or Carboniferous

	UNCONFORMITY
Tremadoc Series	{ Arenaceous Beds
	{ Zone of <i>Shumardia pusilla</i>
	{ Brachiopod Beds
	{ Zone of <i>Clonograptus tenellus</i>
	{ Transition Beds
	{ Zone of <i>Dictyonema flabelliforme</i>

FAULT

Cambrian (Comley Sandstone)

The sequence is constituted mainly of olive-grey weathering, blue-hearted mudstones and shales, which are soapy to the touch, but micaceous flags occur and cone-in-cone structures are not uncommon; towards the top of the succession, the beds become more sandy

¹ Bulman has recently proposed a new family, Anisograptidae, to receive, among other genera, *Clonograptus* and *Bryograptus* which are the 'graptoloids' referred to in the present account; the new family includes those graptodendroid forms which are transitional between the dendroids and graptoloids ('Graptolites from the Dictyonema Shales of Quebec', *Quart. Journ. Geol. Soc. Lond.*, 1950, 106, 68).

² Replaces the homonyms *Psilocephalina* and *Psilocephalus* (Stubblefield, C. J., 1951, 'New names for the Trilobite Genera *Menevia* Lake and *Psilocephalus* Salter', *Geol. Mag.*, London, 88, 213; and 'Further Renaming of the Tremadoc Trilobite Genus *Psilocephalus* Salter', *Ibid.*, 88, 440).

³ (After this footnote was set up in type I received a reprint by T. Kobayashi 'On the Ordovician trilobites in Central China', *Journ. Fac. Sci., Univ. Tokyo*, II, 8, 1, 1-87, which is dated October 30, 1951. Here (p. 72) Kobayashi proposes *Psilocephalinella* in place of the homonym *Psilocephalina* Stubblefield, and because *Psilocephalinella* has precedence over *Borthaspis* Stubblefield, the latter genus is a synonym and should be rejected.)

and the conditions, under which they accumulated, appear to have been adverse to life because few fossils are recorded from them. In general, the lower beds are prolific at some horizons in dendroids and graptoloids, although in addition they contain some unique trilobites, while the upper beds are characterised by trilobite assemblages.

The three other Tremadocian localities, named after the Stiperstones, Lawley and Cardington, are not so well-documented faunistically. An important strike-fault delimits the eastern margin of the Stiperstones outcrop, while to the west the Stiperstones Quartzite of Arenig age reposes unconformably upon shales and flags belonging to the *Shumardia* Zone (Whittard, W. F., 1931, pp. 324, 344). The *Dictyonema* and *Clonograptus* Zones are represented, but nowhere have richly fossiliferous beds been detected (Stubblefield, C. J. and O. M. B. Bulman, 1927, p. 116); furthermore, the incoming of arenaceous beds occurs earlier in the Stiperstones outcrop than in the Wrekin succession. At Cardington, the *Dictyonema* Zone and the overlying Transition Beds have been recognised (*loc. cit. supra*, p. 116), and higher Tremadocian rocks are not likely to be recorded here because of the overstepping Upper Valentian beds. On the south-east flank of Lawley, there is faunal evidence for the *Dictyonema* Zone (Stubblefield, C. J., 1930, p. 58) which extends close alongside the discordant Hoar Edge Grit of the Caradoc Series and again there is little likelihood of higher Tremadocian rocks being identified (Pocock, R. W., *et al.*, 1938, p. 71, fig. 11).

Igneous rocks of two kinds are intruded into the Tremadocian. At Maddocks Hill, situated close to the south-east side of the Wrekin, there occurs what has generally been described as a camp-tonite, but Whitehead has observed that the rock is analogous to albite-diabase or proterobase. The Stiperstones outcrop contains no comparable igneous type, but cropping out at many places are small dykes either of quartz-dolerite or ophitic dolerite (Whitehead, T. H., *in* Pocock, R. W., *et al.*, 1938, p. 74).

THE ARENIG-CARADOC SERIES

The rocks which, by common consent in this country, are included in the Ordovician System are distributed in four districts in Shropshire and the adjacent parts of Montgomeryshire; nowhere have fossils been collected of undoubted Ashgill age and the Ashgill Series is accordingly claimed to be unrepresented (but see p. 163).

The Shelve-Corndon Inlier covers the largest area of approximately forty-three square miles and is the only district which exposes rocks ranging in age from the Arenig to the Caradoc. Apart from the interruption of the war years, the writer has been occupied since 1930 with the detailed mapping of the inlier, which is structurally complicated by innumerable tear-faults, and with the collecting of representative faunas. Faunal lists from the various stratal divisions are published (Whittard, W. F., 1931, pp. 323-34) and the ensuing

account will not repeat that information, which, in any case, is known to be far from complete; the very large fossil collection, which has now been assembled, includes many species new to science; some of the trilobites have been described (Whittard, W. F., 1940a, 1940b) but many are awaiting attention, including the trinucleids and Ogyginae which provide the most promising material for correlation; the identification of these forms has been intentionally delayed until fully representative assemblages are obtained from all the stratigraphical divisions in the inlier; adequate collections not only of the trilobites but also of the brachiopods, ostracods and graptolites should be completed in the next few years. No attempt at the detailed correlation of the Caradoc rocks within the inlier with developments in other districts will be made, but Bancroft has already published his views (Bancroft, B. B., 1933, correlation tables).

The Caradoc area, type-region for the Caradoc Series, extends from near Harnage, where the rocks are involved in the Church Stretton fault-belt, south-westwards to Coston, near Craven Arms. The country at the southern end of this area, including, for example, the Onny River sections, was the scene of Bancroft's notable researches on the faunas of the Caradoc (1928-49); he prepared a manuscript map on which are depicted the outcrops of the various Stages into which he divided the Caradoc Series, and a copy of this map is in my possession. The northern part of the area has been remapped by the Geological Survey (Pocock, R. W., *et al.*, 1938, pp. 79-90).

The two volcanic horizons found in the Breidden Hills invite a misleading comparison to be drawn with the two volcanic episodes represented in the Caradoc Series of the Shelve-Corndon Inlier. Only Caradoc rocks have been identified in the Breidden Hills; they have been correlated with the *Diplograptus multident* Zone and with part of the *Nemagraptus gracilis* Zone (Wedd, C. B., 1932b, p. 52).

The Pontesford outcrop is the most restricted of the Ordovician successions because equivalents of the *multident* Zone are alone to be found there (Pocock, R. W., *et al.*, 1938, p. 90).

(b) The Arenig Series. Representatives of the Arenig, Llanvirn and Llandeilo Series appear only in the Shelve-Corndon district. The Arenig Series is introduced by the massive Stiperstones Quartzite; this is unconformable to the Tremadocian (Whittard, W. F., 1931, p. 324) and forms a pronounced escarpment which can be followed for ten miles. Alternations of thin quartzite and flaggy siltstones comprise passage-beds into the Mytton Flags. Fossils are somewhat sporadic in their occurrence in the Mytton Flags, being rarely found in the coarser-grained flaggy siltstones and commonly met with in the bluish-grey shales. The two zones of the Arenig, viz. *D. extensus* and *D. hirundo*, are represented in the Flags, but the assessment of the

age of the Shelve Church Beds is rendered uncertain by recent mapping, because they occur near the top of the Mytton Flags and a correlation with the top of the *extensus* Zone has formerly been maintained (*op. cit. supra*, 1931, p. 326). The Mytton Flags throughout their thickness of about 3000 feet belong to a mixed facies; shelly fossils are just as common as graptoloids and dendroids, but none is confined to particular lithologies since all the various kinds of fossil organisms are intermingled. As Stubblefield has noted (1939, p. 53), a cryptolithid-cyclopygid-ogyginid assemblage is typical of the Arenig trilobite fauna, but raphiophorids are now known to occupy an important place, and the presence of odontopleurids, such as *Selenopeltis*, marks the appearance of this family in British Ordovician rocks at an earlier date than was previously recorded.

The Mytton Flags are excellently exposed in the several unwooded valleys which drain the western side of the ridge of the Stiperstones, and they reappear in the elongated dome of Shelve Hill where erosion has failed to bring the Stiperstones Quartzite to the surface.

(c) **The Llanvirn Series.** The Hope Shales are soft and easily-weathered rocks, and their junction with the much more resistant Mytton Flags is marked by a pronounced change in topography. The zones of *D. bifidus* and *D. munchisoni* can be clearly identified and, as with the Mytton Flags, all the rocks display a mixed facies, but graptolites are much rarer in the Weston Beds than in the underlying strata.

The *bifidus* Zone here probably attains its fullest development in Britain; excluding the rapidly accumulated Stapeley Volcanic Group, which consists mainly of water-deposited andesitic tuffs (Blyth, F. G. H., 1938, p. 398), the Hope Shales, the Stapeley Shales and the Weston Beds possess an aggregate thickness of approximately 4500 ft. The *Cyclopyge-Placoparia-Barrandia*-fauna of the Hope Shales contains several unusual trilobites which are, in many cases, specifically identical with occurrences in the $D_1\gamma$ beds of Bohemia (Stubblefield, C. J., 1939, p. 54; Whittard, W. F., 1940a, 1940b), and Spencer (1950, p. 398) refers to the ophiuroid starfish *Palaeura* which is likewise found in both regions. Some elements in this trilobite-fauna have also been identified in Pembrokeshire, and data is gradually being accumulated which more and more certainly points to a direct connection existing in *bifidus*-times between Shropshire, Pembrokeshire and Bohemia. Dr. A. Muir, Rothamsted Experimental Station, has proved by X-ray analysis that some cream-coloured clays, thought in the field to be bentonitic, consist of a mixture of illite and montmorillonite, the latter being unusual in showing only limited expansion along the *c*-axis with glycerol treatment.

The interbedded shales of the Stapeley Volcanic Group and the succeeding Stapeley Shales continue to provide mixed faunas, but many of the Bohemian species have disappeared, although the

Cyclopyge-Placoparia-Barrandia assemblage persists; *Ogygiocaris* and *Platycalymene* are now important and these genera are unrecorded from Bohemia.

An upward gradation from the Stapeley Shales into the Weston Beds, as seen for instance in the Holywell Burn, Rorrington, makes it necessary arbitrarily to select a junction between these two stratal divisions. Much more arenaceous matter now enters into the composition of the rocks; the Weston Beds, in some localities, exhibit two horizons of massive flagstones and muddy sandstones alternating with siltstones and occasional shales. In the latter, graptoloids occur indicative of the *bifidus* Zone. Generally, the massive flagstones provide few fossils but, in the more shaly layers and in interbedded tuffs, horizons exceedingly rich in fossils have provided Ogyginae associated with innumerable lamellibranchs, gastropods and horny brachiopods. The aspect of this fauna is unexpected and were it not for the trilobites, a few rare crinoids, some articulate brachiopods and nautiloids, a brackish-water habitat might have been deduced.

The Betton Beds, about 600 ft. thick, record a return to blue-black shales and flags in which graptoloids found in the *murchisoni* Zone are associated with abundant Ogyginae and trinucleids. There is no indication of a gap in the succession at the base of the Betton Beds; indeed the conditions are otherwise, because a lithological gradation exists from the Weston Beds and the junction has to be drawn on faunal criteria, that is, where *D. murchisoni* itself, or the assemblage of the *murchisoni* Zone, appears.

Blyth (1938, p. 397) has described the petrological details of a series of tuffaceous rocks in a typical section of the Stapeley Volcanic Group exposed near Leigh Manor.

(d) **The Llandeilo Series.** The Llandeilo Series, like the Arenig and Llanvirn Series, is recorded in Shropshire only from the Shelve Inlier.

There are two current schools of thought regarding the classification of the rocks particularly in the middle range of the Ordovician. In his review of the evidence, Jones (1936, p. 467) noted that, in the type-areas for the shelly facies, faunas containing *Nemagraptus gracilis* occur at the base of the Bala and of the Caradoc, and he alluded to the existence of lithological and physical breaks in many localities near, or at the base of, the *Nemagraptus gracilis* Zone; the base of the Bala, and of its lower component, the Caradoc Series, should thus be drawn to include the equivalents of that zone. Confirmatory evidence has been adduced recently by Williams who has announced that the Llandeilo Series of Llandeilo excludes the *gracilis*-fauna and is separated therefrom by important lithological and faunal changes.¹ On the other hand, Elles maintains that the

¹ The geology of the Llandeilo District. *Abst. Proc. Geol. Soc. Lond.*, 27 Nov. 1951, No. 1479, 5.

gracilis Zone should be kept in the Llandeilian,¹ being separated from typical Caradocian rocks by passage beds belonging to the zone of *Diplograptus multident* (1937, pp. 488-93). There are difficulties in accepting unconditionally either of these practices, and the urgent need remains for a redefinition of the subdivisions of the Ordovician System acceptable to all opinions, if for no other reason than to remove that confusion which exists in the minds of British and, more particularly, of foreign workers.

Turning to the Shelve area, another problem arises because this appears to have been a locus throughout much of Ordovician times of continuous deposition and no hiatus has been detected in the field between the Betton Beds (*murchisoni* Zone), the Meadowtown Beds (Llandeilo) and the Rorrington Beds (*gracilis* Zone, Caradoc); lithologically the change from one division to another is gradational and, as far as a general study of the faunas has shown, there is no marked break where the Meadowtown Beds give place to the Rorrington Beds, because the lowest horizons of the latter are not truly graptolitic but contain mixed faunas, among which trilobites predominate. The typical Rorrington Beds certainly contain an assemblage characteristic of the *gracilis* Zone, and, for the present, the Meadowtown Beds are classified as the sole representative in Shropshire of the Llandeilo Series.

Tear-faulting is responsible for the failure of the Meadowtown Beds to appear in the southern part of the area, south of Spy Wood. The rocks show considerable variety; much of their thickness of approximately 400 ft. is composed of shales and mudstones, but some thin limestones and calcareous tuffs, because they frequently make exposures, create the impression that they account for a greater proportion of the strata than is actually the case. The famous quarry at the hamlet of Meadowtown was reopened several years ago in order to determine the succession of rocks tabulated below:

	ft.	in.
8. Blue-black, splintery-weathering shales containing graptoloids and Ogyginae intermixed; this is probably the bed which yielded the holotype of <i>Diplograptus foliaceus</i> (Murchison)...	12	0
7. Calcareous, tuffaceous bands with interbedded shales ...	2	4
6. Massive, colour-banded, blue-hearted, calcareous tuff with thin shales... ..	5	10
5. Thin, platy beds of flaggy calcareous tuff	0	8
4. Massive, grey, flinty, calcareous tuff exceedingly rich in matted sponge-spicules and fragmented horny brachiopods...	0	9
3. Greyish-brown weathering, blue-black, hard, decalcified shales with thin, micaceous flags. This is the horizon of abundant <i>Ogyginus corndensis</i> (Murchison)...	8	1

¹ The Llanvirnian is rejected as a subdivision of the Ordovician, the Llandeilian being carried down to include the *murchisoni* Zone and the Arenigian extended upwards to include the *bifidus* Zone; Elles thus adopts the general classification proposed by Marr (Classification of the Sedimentary Rocks, *Quart. Journ. Geol. Soc. Lond.*, 1905, 61, lxxxix-lxxxvi).

	ft.	in.
2. Hard, blue-hearted, calcareous tuff, weathering to 'ginger-bread', rich in shelly brachiopods admixed with broken trinuclids, Ogyginae, horny brachiopods and sponge remains	0	7
1. Blue-hearted, calcareous tuffs, weathering to 'ginger-bread', interbedded with shales showing conchoidal fracture ...	1	2

Approximately 32 ft. of rock were exposed in the quarry but the succession is characteristic of much of the Meadowtown Beds, although true limestones have not been seen in the quarry and neither have the coarse lithic tuffs of other localities. The fauna lacks much variety, but the recent work of Williams¹ promises that a correlation will eventually be effected between the Meadowtown Beds and the Llandeilo succession determined in the Llandeilo-Llangadock district:

(e) **The Caradoc (Lower Bala) Series.** At the dawn of Bala times, the sea swept eastwards from the Shelve area to occupy regions which previously had not received any of the marine Ordovician deposition, and thus, at Pontesford and in the Caradoc area, unconformable relations exist.

Whitehead (1929, p. 120 and in Pocock, R. W., *et al.*, 1938, p. 34) has demonstrated in the Pontesford (Habberley) Brook the presence of shales, sometimes with a basal series of sandstones and conglomerates, resting upon Uriconian and Longmyndian rocks, and there is no indication here of strata older than the *multidens* Zone.

A somewhat similar zonal range occurs at the Breidden Hills where the succession commences with rocks providing what may prove definitely to be a *gracilis*-fauna, but most of the rock-thickness falls into the *multidens* Zone (Wedd, C. B., 1932b, p. 49); nothing is known of any pre-*gracilis* Beds and no unconformity has been recognised. The Breidden rocks may possess greater affinity with the Shelve area than with either Pontesford or Caradoc, next to be described, because Ordovician rocks older than any identified in those places might eventually be proved, say, in boreholes.

The Hoar Edge Grit (Costonian) of the Caradoc type-area has long been known to rest discordantly upon rocks ranging in age from Pre-Cambrian to Tremadocian, but only comparatively recently has it provided specimens of *Nemagraptus gracilis* (Stubblefield, C. J., in Kitchin, F. L., 1930, p. 87), suggesting that a part of the land was flooded at a slightly earlier time than at Pontesford. The country over which the sea was now encroaching was a region of strong relief and the littoral sedimentary zone, present as the basal member of the Caradoc Series, is diachronic; for example, around the Stretton Hills the rock effecting the unconformable contact is of Harnagian and not Costonian age, and the fissures containing the Neptunian dykes on Hazler Hill were filled in early Harnagian times (Strachan, I., *et al.*, 1948, p. 278).

The Caradoc area is astonishingly rich in fossils and in variety of

¹ The Lower Ordovician cryptolithids of the Llandeilo District. *Geol. Mag.*, London, 85, 65-88.

rock-types. Nothing quite like these strata is known elsewhere—their nearest approach is found in the neighbourhood of Bala—and they probably accumulated in an exceedingly shallow shelf-sea where organisms flourished in water approaching a condition of calcium bicarbonate saturation; no thick or important limestone is to be found there but nearly all the rocks, whether they be mudstones, shales, flags, sandstones and grits, either were, or still are, highly calcareous. The geographical distribution of such easily recognised strata is restricted to the country immediately east of, and included within, the Church Stretton fault-zone. Farther west, in the Shelve district, the distinctive lithologies have disappeared, being there replaced by a predominantly argillaceous sequence in which two major, and several minor, volcanic episodes are recorded. Volcanic detritus is incorporated in some of the sediments of the Caradoc district, particularly in the Harnage Shales, but tuffs generally appear to be absent, although they may occur in the unmapped region of Hazler Hill. A thin volcanic agglomerate and a lava flow of weathered trachybasalt, a few feet in thickness, are the only direct evidence known to me of vulcanicity in the Caradoc area. The rocks, which are associated with graptolitic Harnage Shales, are to be seen in an old 'gravel pit' marked on the six-inch map between Hendley Gutter and Bird's Coppice about a quarter-mile north-west of St. Michael's Church, Sibdon Carwood, near Craven Arms.

Lapworth proposed a classification of the Caradoc Series of the classical Caradoc area which was founded on lithological units; in effect, Bancroft (1929a, pp. 33–41; 1929b, table facing p. 76; 1933) has replaced these names, which in any event were unlikely to be applicable outside the area—or for that matter even within—by a palaeontological terminology which is mainly founded upon cryptolithids and brachiopods. Some of the species, on which Bancroft placed a correlation-value, may be facies-fossils and, theoretically, they would be subject to the same disadvantage of all such fossils, that is, prone to give false correlations. Nevertheless, several of Bancroft's zones and subzones have been identified in North Wales, South Wales and the Lake District, and his methods are most promising of results; they warrant, if for no other reason, a restudy of the Bala successions and faunas of these several areas to ascertain how many of the cryptolithids and brachiopods he has selected are tied to lithology.

Space does not permit a reproduction of Bancroft's zonal succession proposed in the Caradoc area nor of his correlation-tables; the latter were privately printed (1933) and his views were further elaborated in a posthumous paper (1945), where he defined (p. 182) the Onnian–Costonian Stages as embracing 'the *Pleurograptus linearis* horizon and part or all of the *Dicellograptus complanatus* horizon above; including part of the *Nemagraptus gracilis* horizon below'. Bulman has subsequently established the presence of inter-

mediate zones because the Harnage Shales can be correlated with the zones of *Diplograptus multidentis* and *Dicranograptus clingani* (1948, p. 227). The quotation from Bancroft implies that, on the graptolitic scale, the topmost beds of the Caradoc sequence are of Ashgill age; this statement is substantiated by another quotation, for in 'Wales and Westmorland the Actonian includes the earliest deposits with *Tretaspis kjaeri*, *Phillipsinella* and other typical upper Bala fossils' (p. 183). Later in the same paper, where he writes of the Girvan district, Bancroft makes the conflicting statement that 'the Actonian and Onnian are represented in the series of grey flags with fossiliferous limestones underlying the zone of *Dicellograptus complanatus* (Pusgillian)' (p. 186), and further confusion arises from his correlation of the Actonian with the zone of *Pleurograptus linearis* (1933, p. 4). Consequently, I find it difficult to discover whether he did, or did not, hold the view that rocks of Ashgill age occur in the type-sequence of the Caradoc area. Lamont¹ has interpreted Bancroft to mean that in the Cross Fell Inlier, and by implication in the Caradoc area also, the Onnian is not to be included in the Ashgill Series.

Turning to the Shelfe area, no obvious physical break has been detected either at the base, or within, the sooty, blue-black mudstones and flags of the Rorrington Beds which yield the *gracilis*- and *multidentis*-faunas, and can be accepted as commencing the Caradoc Series. These rocks offer a remarkably close lithological parallel with the *Dicranograptus* Shales of Wales. In the Spy Wood Burn and in stream-sections elsewhere, they are succeeded by the Spy Wood Grit; there is no definite lithological break and in the Spy Wood Burn about 10 ft. of passage-beds intervene between the typical rocks of the two subdivisions; on the other hand, there is a pronounced facies-change from graptolitic Rorrington Beds to shelly Spy Wood Grit, but again these are separated by the passage-beds, which have not yet provided fossils. The Spy Wood Grit, about 300 ft. thick, possesses a varied fauna among which ostracods are exceedingly abundant (Harper, J. C., 1947, pp. 348 and 351); some years ago Spencer described ophiuroid and asteroid starfishes from a 'lost' locality at Rorrington (Spencer, W. K. and T. Groom, 1934, p. 231), but during the recent mapping a starfish-band has been opened at two localities not far from that village; the band is no more than 1½ in. thick, consists of an argillaceous fine-grained sandstone, and the starfishes, which plentifully occur within it, are restricted to the bed. Elles (1937, p. 484) has claimed that the Spy Wood Grit and Hoar Edge Grit are diachronic representatives of the same sedimentation-zone, but this is probably incorrect because, so far as the scanty graptolitic evidence shows, the Hoar Edge Grit of the eastern outcrop is older than the Spy Wood Grit; since the Caradoc sea inundated land towards the east, overlap would also occur in that direc-

¹ Lamont, A. 1948. B. B. Bancroft's geological work. 2. Upper Ordovician of the Cross Fell Inlier. *The Quarry Managers' Journ.*, London, 31, 416-18, 466-9.

tion, and hence the relative age of these two stratal subdivisions should, if they were diachronic, be the reverse of what it is.

The top of the Spy Wood Grit is also difficult to delineate in the field because these sandy rocks merge into the Address Shales through a thickness of alternating sandstones and shales. A few thin bands of creamy-white, pasty shale occur interbedded in the brown-weathering, bluish-black Address Shales; these are rich in illite and montmorillonite, of which the latter shows the limited expansion along the *c*-axis as already reported by Dr. Muir from clays from the *bifidus* Beds (p. 158). The Address Shales, probably not much less than 1000 ft. thick, had previously been identified with the *clingani* Zone (Whittard, W. F., 1931, p. 333); the record of *Diplograptus multidens*, *Glyptograptus teretiusculus* var. *siccatus* and *Dicranograptus* cf. *ramosus* var. *spinifer* indicates that the *multidens* Zone is also represented (Bulman, O. M. B., 1948, p. 227). Accordingly, the Address and Harnage Shales contain similar faunal elements and are composed of not dissimilar sedimentary types; although these shales have been likened to the *Dicranograptus* Shales, they do not exhibit that lithological resemblance so marked in the Rorrington Beds.

The only other reliable record which points to the existence of higher graptolitic zones in the Shelve area derives from the Hagley Volcanic Group (350 ft.); at Hagley Quarry, collectors of the Geological Survey obtained from water-deposited tuffs a suite of fossils located near the junction of the *clingani-linearis* Zones (Whittard, W. F., 1931, p. 334). The Ordovician history of the Shelve Inlier is concluded by the Hagley and Whittery Shales which are separated by a second volcanic phase recorded in the Whittery Volcanic Group (300 ft.). Bancroft (1933) has equated the Whittery Shales with the Longvillian to Onnian Stages, but the occurrence in the highest fossiliferous horizon of the Whittery Shales of a *Salterolithus*-fauna, also containing *Broeggerolithus*, shows that this correlation cannot be supported. In all probability the greater part of the Longvillian and the whole of the Marshbrookian, Actonian and Onnian are covered by the Upper Valentian overstep. Onnian strata reappear at Welshpool, where Shackleton discovered *Onnia gracilis* in the Gwern-y-brain shales (*in discussion to Whittington, H. B., 1938c, p. 455*); the stratigraphy of this area is in need of revision.

Blyth has demonstrated that the basic intrusions of the Shelve Inlier, which range from picrite, ophitic dolerite, andesine-dolerite to augite-andesite and alkali-rich andesite, belong to one co-magmatic suite having affinities with alkaline plateau-basalt or olivine-basalt (1944, p. 199). The Corndon intrusion was quoted as a laccolithic mass (Watts, W. W., 1925, p. 354), but a careful tacheometrical survey of the hill and a plotting of the geological boundaries have shown that the intrusion is more truly phacolithitic and was emplaced along a pre-existing anticlinal axis (Blyth, F. G. H., 1944, p. 178). The Breidden Hills also contain a doleritic mass which, being com-

CARADOC	Series	SHELVE-CORNDON	Graptolite Zones	BREIDDEN HILLS	PONTESFORD
Onnian } Onny Shales } Upper Acton } Scott Beds	Caradoc				
Actonian } Lower Acton } Scott Beds					
Marshbrookian } Longville } Flags					
U. Longvillian					
L. Longvillian } Horderley } Sandstone Soudleyan } Glenburrell } Beds		Whittery and Hagley Shales with two groups of volcanic rocks	<i>P. linearis</i> <i>D. clingani</i>		
Harnagian		Aldress Shales	<i>D. clingani</i> <i>D. multidentis</i>	Upper Shales U. Volcanic Group	Grey Shales
		Spy Wood Grit	? <i>D. multidentis</i>	Middle Shales	Basal deposits
		Rorrington Beds	<i>D. multidentis</i> <i>N. gracilis</i>	L. Volcanic Group	
Costonian				Lower Shales (Base not seen)	
~~~~~					~~~~~
Pre-Cambrian to Tremadocian	Llandeilo	Meadowtown Beds	? <i>G. teretiusculus</i>		Pre-Cambrian
		Bedton Beds	<i>D. murchisoni</i>		
	Llanvirn	Weston Beds Stapeley Shales Stapeley Volcanic Group Hope Shales	<i>D. bifidus</i>		
	Arenig	Mytton Flags Stiperstones Quartzite	} <i>D. hirundo</i> } <i>D. extensus</i>		
		~~~~~			
		Tremadocian			

pared with Corndon Hill by Watts (*loc. cit.*, p. 356), was suggested by him to be another laccolith.

5. THE SILURIAN SYSTEM

(a) **The Valentian Series.** The incidence of earth movements, elsewhere referred to the Taconian Orogeny (p. 187), towards the close of the Ordovician period and possibly continued into early Silurian times, resulted in major tear-faulting which affected not only the Shelve Inlier but also the Tremadocian of the Habberley outcrop and the Pre-Cambrian of the Longmynd; the Ordovician succession of the Shelve was in addition thrown into an anticline and syncline. Accordingly, when the Lower Silurian sea gained access to south Shropshire, it encroached upon a land-surface of such diversified topography that several areas remained as islands or archipelagos. But the sea, which was in existence early in Silurian times farther west, did not reach this borderland country until the powerful marine transgression of the Upper Valentian, which not only inundated much of what is now Shropshire but also reached beyond to Central and South Midlands, Gloucestershire and Somerset. Graptolites were not numerous in these shallow coastal waters of a shelf-sea, but their remains which have been found demonstrate that the Upper Valentian can at least be correlated with the *turriculatus* and probably the *crispus* Zones; consequently, the sea failed to extend to our area until much later in Upper Valentian times than elsewhere in the west, but it appears to have arrived earlier than in the more southeasterly districts where stratigraphically higher shelly faunas are found. The hills or upland regions of the landscape were the Breiddens, the topographical unit of the Shelve area plus the Habberley Valley and the Longmynd, and the long ridge-like mass or archipelago which has been named the 'Caradoc Ridge' (Whittard, W. F., 1932, p. 860) and which ranged from the Hopesay and Wartle Knoll area in the south, north-eastwards along the general direction of the Church Stretton fault-system at least as far as the Wrekin-Lilleshall district. Long arms of the sea were first established in the valleys between these three hilly masses and a typical rias coast came into being; more and more land became submerged under the enveloping sea, but there is no certain evidence that the highest parts were swamped. The greatest altitude, at which Upper Valentian rocks are now found, is 1222 ft. in the Shelve Inlier; this figure is likely to be misleading because the effects of post-Valentian warping and faulting cannot be discounted. The irregularity of the hard rocky coast provided optimum conditions for the development of pebble-beaches, pebble-banks and sea-stacks,¹ while the existence of valleys on the

¹ The Valentian unconformity in Park Plantation, Plowden, was exposed in an excavation dug over 20 years ago (Whittard, W. F., 1932, fig. 3, p. 894 and pl. 58). This section usually becomes covered in a few years and further excavations, made on various occasions for visiting parties of geologists, have proved that the smallest sea-stack indicated both in fig. 3 and on the right of pl. 58 (*op. cit. supra*) is faulted against the Valentian rocks. The throw of this fault is small and does not materially affect the interpretation of the relationships of the strata at this locality, viz., sea-stacks of Longmyndian rocks surrounded by the arenaceous deposits of Valentian age.

Longmynd and on the Shelve can be established by the behaviour of the basal Valentian rocks (Whittard, W. F., 1932, pp. 890-6). Debris, derived from the east of the Longmynd, is included in the Valentian conglomerates and the exposure of this region to weathering seems to have happened about this time, because older Palaeozoic rocks are not anywhere known to possess unconformable contacts with the Stretton 'Series'. As already mentioned (p. 147), the rocks of the Wentnor 'Series' are believed to have acted as a mantle to the Stretton 'Series', and this cover was not penetrated until the onset of the Silurian period. Another conglomerate, situated within the *Pentamerus* Beds and rich in Uriconian pebbles and pentamerids, is restricted to the south-east side of the Wrekin, and indicates active erosion of this hill during Upper Valentian times (Whittard, W. F., 1928, p. 745).

The Valentian rocks dip away from the eastern flank of the south-west spur of the Longmynd at an angle of about 25 degrees. If the Valentian rocks be restored to a horizontal position, as advocated by some geologists, the westerly dip of 70-80 degrees in the Stretton 'Series' would become easterly, and the ascending stratigraphical order in the Stretton 'Series' would thus be easterly, instead of westerly. The fallacies in this reasoning are evident when the behaviour of the Valentian rocks encircling much of the Longmynd-Shelve Inlier is examined. When the directions of dip of the Valentian rocks at all the exposures are placed on one diagram they are found 'to box the compass', and if the rocks on the south-east side of the Longmynd are returned to a presumed original horizontal position, then all other Valentian rocks must be similarly treated. The result would be chaotic, and identical stratigraphical successions in the Longmyndian rocks themselves would in one place be ascending, and in another descending, in sympathy with the change-over in direction of dip of the Valentian rocks. That wrong conclusions are reached regarding the age-relationships of members of the Stretton 'Series' when the Valentian rocks are put back to a horizontal position, is now clear to see; in any case, nowadays there is much more reliable evidence available on which to ascertain the stratigraphical top of the strata comprising the Longmynd. The amount of inclination of the Valentian rocks can be explained by attributing a large part of the angle to an original depositional dip, subsequently increased by differential compaction of the sediments. Where deposition occurred in narrow gulfs bounded by steep rocky coasts, as, for example, between the Longmynd and the Caradoc Ridge, and along the Minsterley-Hope valley, the deposition-compaction angle on opposite shores would automatically provide a synclinal structure which was strictly depositional, and not tectonic in origin. In the writer's opinion, only a few of the 25 degrees of tilt, usually recorded in the Valentian rocks skirting the Longmynd, Shelve and Breidden masses, can be attributed to tectonic causes.

Lithologically and faunistically the Upper Valentian is readily divided into the *Pentamerus* Beds, locally rich in *Pentamerus oblongus*, surmounted by the Purple Shales from which this brachiopod is absent except as a derived fossil. The faunal contrast between the two subdivisions has been proved by recent studies to be so pronounced that a time-interval of as yet undetermined importance may separate them (Smith, S., 1930; Whittard, W. F., 1938; Pitcher, B. L., 1939; Harper, J. C., 1940; Whittard, W. F. and G. H. Barker, 1950); as is frequently the case in other rocks, the faunal change is not accompanied in the field by evidence of disconformity.

The *Pentamerus* Beds and the Purple Shales both exhibit marginal arenaceous deposits, although the bulk of their thickness is composed of shales with subsidiary limestones. For example, conglomerates and sandstones are often developed where the *Pentamerus* Beds are in unconformable contact at various localities with rocks which may range in age from Uriconian to Caradocian; this is not invariably the rule for notably at Norbury and in the Minsterley area, but also elsewhere, the succession commences with argillaceous rocks and only rarely may a conglomerate a few inches thick, representing the washed-off waste derived from the immediately adjacent land-surface, be present. The Purple Shales exhibit a basal arenaceous condition in some of those regions, but not at the Onny Section, where they have overlapped the *Pentamerus* Beds; the high-level outliers of the Bog Mine and of Bank, near Minsterley, are good examples.

Contrasted with the differences of facies which exist in later Silurian strata, the Upper Valentian rocks are typically shelly and the sea at this time was extremely shallow everywhere where its deposits are available for examination.

(b) The Wenlockian Series. True heteropism is presented by the Wenlockian rocks because along the Wenlock Edge and its south-westerly continuation, in the All Stretton Inlier and in the structurally complex Brokenstones area, a shelly facies finds its time-equivalents in the completely different succession of the graptolitic facies of the Long Mountain and of the Camlad and upper Onny valleys. The Wenlockian, exposed south-west of Minsterley, is anomalous as it provides no graptolites and, indeed, not much in the way of shells either; the rocks are, perhaps, nearer the shelly facies and they can be considered as an outpost amongst graptolitic facies owing their local peculiarities more to the proximity of the landmass of the Shelve than to regional geography.

The pronounced lithological change between the Purple Shales and the Wenlock Shales, the lack of evidence for the *griestonensis* and *crenulatus* Zones at the top of the Upper Valentian, and the absence at different places along the outcrop of one or more of the lowest zones of the Wenlockian amply demonstrate the unconformable,

and not the overlapping, relationship of the Wenlockian with the Valentian. The hiatus in the stratigraphical record points either to land-emergence or to an extreme shallowing of the sea, and implies an extension into Silurian times of that uneasy tectonic condition which set in towards the end of Ordovician deposition. Oscillations of the south-east margin of the trough of deposition developed other intraformational discontinuities, such as occur in the Long Mountain where the *rigidus* Zone cuts out the *linnarssoni* Zone, there being no representatives of the *symmetricus* Zone, and also in the Ludlovian where *leintwardinensis* Beds are in direct contact with *nilssoni* Beds. All these breaks in the record are associated with the type of lithology embodied in the 'Buildwas Beds'; here olive-green and brown friable mudstones, occasionally containing small pebbles, are charged locally with innumerable stunted fossils associated with fragments of larger shells; large, whole fossils are rare. The aspect of the Buildwas Beds suggests deposition in water so shallow that wave-action not only rendered the sea turbid but broke many of the larger brachiopod valves, and the inimical physical conditions produced a dwarfed community. These conditions did not necessarily occur at the same period but were likely to arise any time in the Wenlockian (and the Ludlovian) when the instability of the shoreline produced the required physical environment.

The simple syncline of the Long Mountain, gently pitching to the north-east, provides a well-exposed sequence of graptolite-rich, flaggy mudstones and shales, in places carrying subordinate, irregular and sometimes nodular calcareous bands; shells are usually restricted to the 'Buildwas Bed'-type of lithology which has been recognised at the base of the *linnarssoni* and at the top of the *lundgreni* Zones (Das Gupta, T., 1932, p. 345). The oldest Wenlockian strata identified in the syncline are attributed to the *riccartonensis* Zone and are known only from one small quarry behind Walcot Farm, Chirbury; this zone is certainly undeveloped at the surface in the west and north where contacts with pre-Wenlockian beds exist either with the *linnarssoni* Beds, or, where these have been overlapped, with the *rigidus* Beds. The *murchisoni* Zone is missing in the Long Mountain as it may also be elsewhere to the south-east; in the Plowden and Snead areas the Purple Wenlock beds consist of alternations of greenish-brown and purple shales and, although modified, are comparable with the Buildwas Beds; these quickly give place, within 40 ft., to typical shales containing shells but also providing graptolites, and once, in conversation, Das Gupta said that he had found evidence of the *murchisoni* Zone near Plowden (Whittard, W. F., 1932, p. 869).¹ The greenish-brown flags of the Wenlock Shales of the Wistanstow area were referred to the *murchisoni* Zone on what is now realised to be insufficient graptolitic evidence. Das Gupta's equation of the Minsterley sediments with this zone rests

¹ The *murchisoni* Zone may also occur west of the Church Stretton Fault (F1) at Sharpstones.

upon the record of *Dalmanites caudatus* (Brünnich) and a superficial similarity with the succession described from Meifod. Returning to the Long Mountain, the *lundgreni* Zone completes the sequence; appearing about 100 ft. up from the base and continuing through the succeeding 100 ft. of flags and shales, are many calcareous concretions sometimes attaining a breadth of two or three feet. The maximum thickness of the Wenlockian is of the order of 1500 ft. of which the *lundgreni* Zone accounts for two-thirds.

The classical development of the Wenlockian along the type-area of the Wenlock Edge is strikingly different from the sequence described from the Long Mountain, and the greatest thickness is composed of a soft friable shale. Due to the rich fauna and lithological interest of the Wenlock Limestone, attention is apt to be focused on this horizon which, however, occupies at the most no more than about one-tenth of the total thickness. The Buildwas Beds introduce the Wenlock Shales and have already been mentioned; it was from rocks exposed in the northern bank of the Severn that rich collections of dwarfed brachiopods, trilobites and other shelly forms were concentrated by elutriation in a wash-tub, the shale being broken down with a posser. The few graptolites that the rocks provide do not warrant correlation with any zone older than *linnarssoni*. Occurring within the Buildwas Beds and, indeed, at many other levels in the Wenlock Shales, are cream-coloured clays which X-ray analysis may prove to be bentonitic. The Geological Survey identifies the overlying Lower and Middle Coalbrookdale Beds with the *rigidus* and *lundgreni* Zones; while the Upper Coalbrookdale and Tickwood Beds, the latter forming a gradual transition by increasing content of calcareous nodules to the Wenlock Limestone, have yielded at several localities many specimens of *Gothograptus nassa* (Pocock, R. W., *et al.*, 1938, p. 101). According to Das Gupta (1935, p. 110) the associated monograptids of *flemingi*-type indicate the *lundgreni* Zone, which accordingly provides the lower limit for the age of the Wenlock Limestone. On the other hand, the existence of the *vulgaris*-fauna above the Limestone does not automatically prove that the Limestone occupies a position at the top of the *lundgreni* Zone, for, as the Survey has observed (Pocock, R. W., *et al.*, 1938, p. 102), it might belong there, or be the equivalent of the lower part of the *vulgaris* Zone, or occupy a place about the junction of the Wenlockian and Ludlovian. Where the Wenlock Limestone cannot be recognised, the *vulgaris* Zone is usually well-developed, and the tempting, but possibly too simple, explanation is that the Limestone replaces the argillaceous lower part of the *vulgaris* Zone. What is now needed is, first, a careful study of the Wenlock Shales and Limestone along the Wenlock Edge in that direction to the south-west where the Limestone becomes thinner, in order to establish whether a *lundgreni*- or a *vulgaris*-fauna replaces the Wenlock Limestone; and, secondly, much more knowledge of the brachiopod

faunas is desirable, particularly of the Wenlock Shale, because a detailed examination of these admittedly facies-fossils might show a more reliable, and a more workable, zonal arrangement than the graptolites offer in the solution of this problem.

The maximum development of the Wenlock Limestone is situated in the north-east of the outcrop where there is a difference in altitude of nearly 600 ft. between Apedale and the summit of the escarpment; south of Craven Arms, the escarpment is subservient to that of the Aymestry Limestone and is only about 150 ft. above the lower levels occupied by the Wenlock Shales. The limestone there is much less thick.

The Wenlock Limestone has long been famous for the fossils it yields and evidently certain types are most abundant in differing lithologies; for example, the platy polyzoal limestones are readily distinguished from the crinoidal limestones which again can be separated from the algal and from the brachiopod-trilobite limestones. A study of the palaeoecology of the Wenlock Limestone would pay a good geological dividend, as would further work on the reef-knolls which are known locally as ballstones. 'A ballstone is a reef rock formed *in situ* at a locus of intense activity of coral, stromatoporoid and algal growth' (Hill, D., *et al.*, 1936, p. 131). The reef-rock is an unstratified limestone formed from a fine calcareous mud, and contains fossils frequently preserved in their position of growth; of minor interest are specimens showing stromatoporoids which have utilised the upper surfaces of dead favositids as substrata upon which to build their skeletons. A reef-knoll may develop in any part of the Wenlock Limestone, but, according to Robertson (Pocock, R. W., *et al.*, 1938, p. 115), not usually in the topmost crinoidal limestone; a knoll commences from an almost flat base, and can be traced upwards as a series of superimposed lenses which may traverse most of the thickness of the Limestone. The fossil material concentrated in a knoll often exceeds the amount of sediment in the rock in which it is contained; consequently, a lesser thickness of the adjacent stratified limestone is likely to have been laid down during the time taken for the accumulation of any particular knoll. As claimed many years ago by Twenhofel for the Gotland reefs,¹ the stratified limestone, contemporaneous with the summit of the knoll, does not lie level with that position but is represented by rock occupying a lower place on the flank of the knoll.

The shelly facies of the Wenlockian can be examined to the west of the Wenlock Edge in the All Stretton Outlier and, in a modified form, in the Brokenstones district; both these outcrops are limited, the former on the east and the latter on the west, by the most westerly of the Church Stretton faults, that is, F1 of Cobbold (1927, p. 565). At the Brokenstones, F1 brings the westerly inclined Wenlockian of the

¹ Twenhofel, W. H. 1916. An interpretation of the Silurian section of Gotland. *Bull. Mus. Comp. Zool.*, Cambridge, Mass., 56 (Geol. Ser. 10), 348-53.

west of the 'Caradoc Ridge', which exhibits a condition intermediate between the true graptolitic and shelly facies, almost in contact with the easterly dipping graptolitic development of the south-east side of the Longmynd (Whittard, W. F., 1932, p. 862, fig. 1). This facies-change is surprisingly abrupt, and the change from a shelf-sea on the east to deeper water on the west, along the line of the Church Stretton disturbance, again became operative in Wenlockian times, although there is no indication in the Upper Valentian record that this line was significant or in any way effective with regard to facies. In the Upper Valentian physiography, the Church Stretton disturbance of those times was associated with the 'Caradoc Ridge', which existed as a land-barrier extending from Hopesay to the north of the Stretton Hills, and separated the sea of the Main Outcrop on the east from that which lapped against the east flank of the Longmynd on the west.

(c) **The Ludlovian Series.** The facies differences, already noted in the Wenlockian, can be recognised in the Lower Ludlovian wherein a western series of graptolitic rocks are contrasted with the shelly rocks found to the east beyond the Wenlock Edge; but, as will be seen later, graptolites are more abundant in the shelly facies than is the case in the Wenlockian. The sudden and complete disappearance in Britain of graptolites at, or near, the top of the Lower Ludlovian—the cause of this extinction has never adequately been explained—was immediately succeeded in Shropshire by the appearance in the faunas of more lamellibranchs, gastropods, horny brachiopods and worm-like animals, suggestive of the approach, if not the arrival, of slightly brackish-water conditions. That the sea had become more brackish is indicated not so much by the increased importance of these fossils but by the absence, or paucity of species, of those animals which in the Silurian period are obviously marine, viz., trilobites, articulate brachiopods, corals, crinoids and nautiloids. At some time during the Downtonian epoch, brackish water was probably locally isolated into lakes, and either the salinity was diluted or new freshwater lakes appeared; by now the terrestrial conditions of the Old Red Sandstone were established and the arm of the Silurian sea had disappeared from the landscape.

When originally the boundary between the Wenlockian and Ludlovian was drawn on the graptolite-scale, the junction was selected at the base of the *vulgaris* Zone, not because it was sharply delineated but because the *vulgaris*-fauna is closer to the succeeding Ludlovian assemblages than to those of the Wenlockian.¹ The *vulgaris* Zone was admittedly transitional and this is also its character in the graptolitic development of the Long Mountain where, lithologically, the change from the Wenlockian to the Ludlovian is not easy to detect. Das Gupta (1932, p. 334) has supplied the fullest account of the

¹ Wood, E. M. R. 1900. The Lower Ludlow Formation and its graptolite-fauna. *Quart. Journ. Geol. Soc. Lond.*, 56, 421.

Lower Ludlovian of this district, where he has recognised the five graptolite zones established by Wood, except that of *Monograptus scanicus*. Before doubts of the validity of most of these Ludlovian zones had been expressed in print (Earp, J. R., 1944, p. 181), the *scanicus* Zone had been under suspicion and had generally, in Shropshire at least, been classified with the *nilssoni* Zone. The *leintwardinensis* Beds cut out the *tumescens* Beds along the northern limit of the Long Mountain syncline, east of Garbett's Hall. No Aymestry Limestone is present but calcareous flags are recorded from the *leintwardinensis* Zone, and towards their base, where the 'Buildwas Beds'-lithology is developed, some few fragments of *Conchidium knighti* have been collected. The blocky mudstones, the sandy flags and the bands of comminuted shells suggest that the graptolite-rich series of the Long Mountain accumulated in much shallower water than is generally assumed for this type of facies. The rocks approach close to the original landmass yet no littoral sediment has been detected; it is probable that the nearby land-surface of the Breiddens and Shelve had become almost, or completely, submerged in Lower Ludlovian times, and the amount of coarse detritus delivered into the sea was small. The remainder of the succession of the Long Mountain has been described by Austin (1925, p. 381) who records the *Dayia* Shales, *Camarotoechia* Beds and *Chonetes* Beds; resting upon the latter is the Downton Castle Sandstone, there being no representative of the Ludlow Bone Bed, and the youngest rocks exposed are the Temeside Shales.

The five zones of the Lower Ludlovian were determined at Ludlow and Builth,¹ but at Ludlow the basal beds, correlated with the *vulgaris* Zone, are unproductive of graptolites, and the *scanicus* Zone is grouped with the *nilssoni* Zone because it cannot be separately identified. When the outcrop is traced north-eastwards beyond Craven Arms, the *vulgaris*-fauna reappears and it has been recorded by Das Gupta (1932, p. 351) 100 ft. above the Wenlock Limestone at Millichope; here he places 140 ft. of strata in the zone, but near Wenlock the *vulgaris* Beds are reduced to a thickness of no more than 60 ft. Again, as at Ludlow, the *scanicus*-fauna cannot be separated because it is intermingled with the assemblage carrying the *nilssoni*-fauna. *M. chimaera* occurs as a typical species of the *tumescens*-fauna and suggests that those beds at Clun, which contain spinose graptolites of the *chimaera*-type, are reasonably to be correlated with the *tumescens* Zone although the index-fossil is there absent (Earp, J. R., 1944, p. 182). Earp believes that, in the Clun area, the middle three zones of the Lower Ludlow have but little stratigraphical value, and he states that the *nilssoni* graptolite assemblage of Clun can be equated on the evidence of the associated shelly fossils with the *scanicus* Beds of Builth; this attributes to the shelly faunas an infallibility for correlation which probably they do not deserve. Neverthe-

¹ Wood, E. M. R., *op. cit.*, 423-40.

less, some of the Ludlovian graptolite zones are unsatisfactory and particularly is this true of the *scanicus* Zone.

The Lower Ludlow Shales, exposed in many of the streams which drain the dip-slope of Wenlock Edge, are rich in shelly fossils, and they are more thoroughly intermixed with graptolites than in any earlier Silurian deposit. If these Ludlovian strata accumulated in a shallow shelf-sea, graptolites must have drifted unimpeded into the coastal regions because at several horizons they provide as important a content of the mixed fauna as the shells.

The Aymestry Limestone attains a maximum thickness of 150 ft. and shows three pronounced lithological conditions (Alexander, F. E. S., 1936, p. 104). A fine-grained nodular limestone frequently contains fossils in their position of growth; a coarse-grained purplish limestone occurs in wedges showing false-bedding; shell-banks and lenticles are almost entirely composed of the shells of single species of brachiopods, witness the famous shell-bank of *Conchidium knighti* at Weo Edge where the majority of the disarticulated valves are orientated with their concave surfaces facing upwards. Alexander has shown that the Aymestry Limestone ascends stratigraphically towards the east; at Shelderton the base lies about the middle of the *tumescens* Zone and farther east it is found within the *leintwardinensis* Zone but fails to reach the top of that zone (*op. cit.*, p. 109). The summit is not infrequently eroded, and an unconformable relationship has been proved north and south of Leintwardine; here the *Dayia* Beds not only cut out the Aymestry Limestone but come to rest on the *tumescens* Zone and at Church Hill, the farthest locality to the west, on the *nilssoni* Zone. The positions of maximum development of *Conchidium* shell-banks and of current-bedded limestone, and where the base of the Aymestry Limestone crosses from the *tumescens* Zone to the *leintwardinensis* Zone, all lie along lines which trend subparallel to the Church Stretton fault. Alexander argues that the Limestone originated on a submarine ridge which grew as a direct result of the unequal sedimentary loading of the seabed on the west of the fault-system as compared with the much less heavy deposition in the shelf-sea to the east. The Aymestry Limestone significantly reaches its maximum where it faces the area of greatest deposition on the west, which was situated between the relatively stable regions of the Bulth and of the Longmynd-Shelve areas.

The Aymestry Limestone is a facies of restricted distribution, because north-east of Craven Arms it is split into subordinate nodular limestone-bands separated by shales; near Wenlock no important limestone occurs and the dominant lithology is a calcareous mudstone. The Aymestry Limestone thus attains its maximum development in the south-west of the outcrop, and is in marked contrast with the thick and massive Wenlock Limestone which occurs in the north-east. The two escarpments due to these limestones thus attain their maxima at the topographical extremities of Apedale. In

TABLE IV. CORRELATION OF SILURIAN ROCKS
(Asterisks denote a direct correlation)

Series	Zones	Long Mountain	Wenlock Edge	Ludlow
Part of Downtonian	Ludlow Bone Bed	Unidentified	* * *	* * *
Ludlovian	<i>Chonetes striatellus</i>	* * *	* * *	* * *
	<i>Camarotoechia nucula</i>	* * *	* * *	* * *
	<i>Dayia navicula</i> and <i>M. leintwardinensis</i>	* * *	Aymestry Lime- stone Group	Aymestry Limestone (in places, base in <i>tumescens</i> Zone) ¹
	<i>M. tumescens</i>			
	<i>M. nilssoni-scanicus</i>	* * *		* * *
	<i>M. vulgaris</i>	* * *	* * *	Barren of graptolites
Wenlockian			Wenlock Lime- stone	
	<i>C. lundgreni</i>	* * *	{ Tickwood Beds Upper Coal- brookdale Beds Middle Coal- brookdale Beds	Zones as
	<i>C. rigidus</i>	* * *		
	<i>C. linnarsoni</i>			
	<i>C. symmetricus</i>	* * *	{ Lower Coal- brookdale Beds Buildwas Beds	yet
	<i>M. riccartonensis</i>	Absent Only at Walcot		
	<i>Cyrtograptus purchisoni</i>	Unidentified, except possibly at Plowden and at Sharpstones	{ Probably absent	unmapped
Upper Valentian	<i>M. crenulatus</i>		absent	
	<i>M. griestonensis</i>		absent	
	<i>M. crispus</i>	{	Purple Shales	
	<i>M. turriculatus</i>		<i>Pentamerus</i> Beds	
	<i>Rastrites maximus</i> to <i>Monograptus sedg- wicki</i>		 absent	

¹ A local unconformity occurs near Leintwardine under the *Dayia* Shales which may cut out the Aymestry Limestone.

the appended paper (p. 201) Dr. Shirley provides a short account of the Ludlovian rocks north-east of Craven Arms. North-east of Wenlock the outcrop terminates near Posenhall against the unconformity of the Middle Coal Measures of the Coalbrookdale field and the last appearance is in the inliers of the Dean and Linley Brooks (Robertson, T., 1927, p. 81).

The greater part of the thickness of the *Dayia* Beds falls naturally into place at the top of the *leintwardinensis* Zone, and whether the deposition of these beds outlived the last of the graptolites in this country or not, they are succeeded by mudstones and flagstones of the Upper Ludlow. A division into *Camarotoechia* Beds succeeded by *Chonetes* Beds has been proposed but, just as there is doubt of the usefulness of some of the Lower Ludlovian graptolite zones, so is there difficulty at present in upholding the real value of a subdivision founded on these facies-fossils.

The Ludlovian epoch saw profound changes, occurring as it did between periods of well-established marine environments on the one hand and terrestrial conditions on the other. Variable and unstable conditions, particularly in the more shallow coastal waters, may be assumed to have existed, and it is under such conditions that facies-faunas attain their maximum expression; hence, the difficulty which attends the subdivision and correlation of Ludlovian strata is no more than need be expected.

6. THE OLD RED SANDSTONE SYSTEM

The Siluro-Devonian junction has provided a subject for controversy over many years. Whether the base of the Devonian should be taken at the base of the Downtonian, or at the base or at the top of the Dittonian, cannot appropriately be discussed here, because it would involve the much larger problem relating to the merits of priority, diastrophism and palaeontology in the delimitation of geological Systems. White (1950a, fig. 2) has reviewed in tabular form the many classifications, which have been favoured by investigators starting with Murchison in 1839, and has maintained a well-reasoned argument in favour of excluding the Downtonian from the Silurian. The Downtonian is here included in the Devonian System because there is a reasonable correlation in part, at least, with the Gedinnian of the Continent, which is usually accepted as the lowest member of the Devonian. Furthermore, the Downtonian is either unconformable to the Silurian or shows a marked lithological change.

Wickham King reawakened interest in the Old Red Sandstone by his careful collecting and recording of fishes particularly in the West Midlands and Wales (1925, p. 383, and 1934, p. 526). He subdivided the Downtonian and Dittonian into ten and four parts respectively, and his notation has been generally adopted. It is becoming apparent,

however, that these are lithological divisions, and, deposited as they were during a period of shifting shore-lines and of local deposition involving estuarine, deltaic, lacustrine and sometimes marine environments, they are not infrequently misleading. A palaeontological classification founded on fish remains may be criticised as being premature, but this is the evidence on which logically to divide the Old Red Sandstone, and a zonal succession is now emerging as more and more research on the fishes is completed. The succession, given in Table V, is most readily applicable to the borderland country (White, E. I. and H. A. Toombs, 1948, p. 5; White, E. I., 1950a, p. 53).

TABLE V. DIVISIONS AND ZONES OF THE OLD RED SANDSTONE

Upper Old Red Sandstone	{	Farlovian	<i>Bothriolepis</i>
			UNCONFORMITY
Lower Old Red Sandstone	{	Breconian (Brownstones)	{ Barren Beds <i>Rhinopteraspis dunensis</i>
	{	Dittonian	{ Barren Beds <i>Pteraspis crouchi</i> <i>Pteraspis (Simopteraspis) leathensis</i>
	{	Downtonian	<i>Traquairaspis symondsi</i>
			<i>Traquairaspis pococki</i>
			Interval with fish fragments
			<i>Hemicyclaspis</i> ¹
			<i>Cyathaspis</i> ¹
			Ludlow Bone Bed

LITHOLOGICAL BREAK

Silurian { Ludlovian

The Ludlow Bone Bed can be followed for a distance exceeding twenty miles from near Much Wenlock to Ludlow (Robertson, T., 1927, p. 91), but nowhere has it been reported from west of the Church Stretton fault-zone. It is composed of one or more layers each of which is seldom more, and usually much less, than two inches thick. The rock has all the appearances of a concentrated remanié deposit; its origin is probably intimately associated with the winnowing-action of currents, the selfsame currents removing the sediment, and thus allowing the bony material to accumulate on the otherwise bare sea-bed. The bone-bed consists of innumerable thelodont scales, spines of *Onchus* and fragments of *Cyathaspis* and *Sclerodus*, the latter marking the appearance of the cephalaspids; associated with these in a rock, which has the appearance of ginger-bread and

¹ *Hemicyclaspis murchisoni* has recently been recorded from the Gornal Sandstone (Ball, H. W. The Silurian and Devonian Rocks of Turner's Hill and Gornal, South Staffordshire. *Proc. Geol. Assoc.*, 1951, 62, 232). The Gornal Sandstone with *Hemicyclaspis* is correlated with the Downton Castle Sandstone with *Cyathaspis*; hence the *Cyathaspis* Zone of Table V appears to be redundant since it can possibly be included as the lower portion of the *Hemicyclaspis* Zone.

is rendered coherent by a calcareous cement, are fragmentary eurypterids, rare *Platyschisma helicites*, brachiopods such as *Chonetes striatellus* and *Orbiculoidea*, ostracods and innumerable phosphatic concretions. The occurrence of marine and brackish, or even fresh, water genera contrasts with the Upper Ludlow; the appearance of fishes in numbers is probably ecological in origin and it should not be overlooked that cyathaspids, thelodont scales and *Onchus*, although exceedingly rare, have been recorded from the Ludlovian (Straw, S. H., 1927, p. 88). A physical break cannot be proved at the base of the bone-bed, but a lithological change may point to a discontinuous sequence from the Ludlovian to the Downtonian; in South Wales, Straw has proved the Downtonian to be unconformable because there the Tilestones are in some places in contact with Ludlovian beds correlated with the zone of *Monograptus leintwardinensis*.¹

The Grey Downtonian in the Ludlow area includes the Downton Castle Sandstone which at Kington and elsewhere provides *Cyathaspis* and eurypterids and, in most places, *Lingula minima*; of interest, is the appearance in Britain of terrestrial plants. The succeeding red and green Temeside Shales contain *Hemicyclaspis* and *Thyestes* among the cephalaspids, *Lingula cornea*, eurypterids, ostracods and dwarfed lamellibranchs and, although difficult of proof, the assemblage has the mark of a fresher water habitat.

The greater part of the Downtonian succession is occupied by the Red Downtonian which is composed of red and purplish marls, generally unproductive of fossils, but, near the top, sandstones assume a greater importance and they are commonly accompanied by vertebrates among which the genus *Traquairaspis* is outstanding (White, E. I. and H. A. Toombs, 1948, p. 7). About this level the so-called *Psammosteus* Limestone is met; no recognisable fossils have been recovered from it, *Traquairaspis* being found in sandstones above and below; the limestone apparently occupies varying stratigraphical levels ranging from within the zone of *Traquairaspis symondsii* to within that of *Pteraspis leathensis*. The limestone is variable in thickness, lenticular, discontinuous and may occur at several levels in the same section; it would appear that calcareous sedimentation took place only when chemical conditions were satisfied for the precipitation of calcium carbonate, and, as with so many older Palaeozoic limestones, the *Psammosteus* Limestone is probably not strictly diachronic, that is, in the original meaning of Wright² (but see White, E. I., 1950b, p. 70).

The Dittonian-Downtonian junction is most logically drawn where *Traquairaspis* is replaced by *Pteraspis*; the only two common fish genera which straddle that junction are *Cephalaspis* and *Anglaspis*.

¹ Straw, S. H. 1930. The Siluro-Devonian boundary in South-Central Wales. *Journ. Manch. Geol. Assoc.*, 1, 99, fig. 4.

² Wright, W. B. 1926. Stratigraphical diachronism in the Millstone Grit of Yorkshire. *Rep. Brit. Assoc.*, Oxford, 354.

Generally considered, the Dittonian is more arenaceous than the Downtonian, while cornstones, which may owe their origin to periods of greater aridity, are characteristic. The dominant fishes are *Pteraspis* and *Cephalaspis*, and of the fifty species of the latter, which have been described, very few are of more than the most local distribution; some localities, indeed, appear to possess their own species unknown elsewhere (White, E. I. and H. A. Toombs, 1948, p. 7).

The Dittonian is followed by false-bedded sandstones, conglomerates and flags with shales; *Rhinopteraspis dunensis* is recorded from the lower horizons and these are probably comparable with the Senni Beds of South Wales, while the remainder of the Brownstones there can be equated in part with the rest of the sequence in the Clee Hills up to the unconformity separating the Farlow Sandstone. In the Clee Hills, the Farlow Sandstone, containing *Holoptychius* and *Bothriolepis* and of Upper Old Red Sandstone age, is lithologically discontinuous with the Brownstones; the unconformable relationship is underlined by the absence of faunas of the Middle Old Red Sandstone.

Dr. Ball and Dr. Dineley, who are engaged with the detailed stratigraphy and palaeontology of the Clee Hills, have provided a geological account in a subsequent paper (p. 207).

7. THE CARBONIFEROUS SYSTEM

Throughout the greater part of the Carboniferous Period, much of southern Shropshire was a province of St. George's Land and received sediments only during the deposition of the Morganian. But to the east of this elevated core of ancient rocks, at Little Wenlock and Lilleshall, and to the south-east, at Titterstone Clee, restricted outcrops of Lower Carboniferous strata occur and, in addition, at these places much, but probably not the whole, of the Ammanian is also represented.

In the isolated occurrence at Titterstone Clee, Dixon refers to limestones of Tournaisian (Lower Dinantian) age; these rest conformably upon the Farlow Sandstones, which are the local representatives of the Upper Old Red Sandstone, and they pass upwards into the Cornbrook Sandstone, attributed to the C₂ Subzone and indicative at least of the lower part of the Visean (Upper Dinantian) (Dixon, E. E. L. in Whitehead, T. H., *et al.*, 1928, p. 42).

South-east of the Wrekin, in the neighbourhood of Little Wenlock, the Carboniferous Limestone contains no equivalent of the Tournaisian and most of the rock-sequence can be correlated with the *Dibunophyllum* Zone at the summit of the Visean. The basal Lydebrook Sandstone yields a fauna typical of the D₁ Subzone; deposition may have commenced a little earlier at Lilleshall, where the upper part of the *Seminula* Zone has been detected. The Lower Carboniferous stratigraphy of Little Wenlock and Lilleshall is therefore strikingly contrasted with that of Titterstone Clee.

The high content of arenaceous material, including wind-worn sand-grains, in the rocks at all these three localities, is yet another indicator of their intimate relationship with the adjacent land-surface on the west. This highland region has been shown, in various physio-graphical reconstructions, as being in continuous extension towards the east with a ridge situated in the Midlands; this ridge separated the two provinces in which the strata of Little Wenlock and Lilleshall were deposited to the north compared with the accumulation at Titterstone Clee to the south. But the continuity of this land-barrier is to be doubted, because the behaviour of the outcrops at these three localities is such as to present a picture of shoreline deposition along a coast trending more north and south than east and west. Wills (1951, pl. 6, B, C and p. 24) has recently given his opinion that the Tournaisian sea may have connected through a gap which separated St. George's Land on the west from a Midland Barrier on the east, and that rocks of this age have been removed by erosion consequential to elevation caused by mid-Dinantian movements. In this manner, the violent unconformity, which the Visean of Little Wenlock shows with the Tremadocian and Silurian, is explained.

Pocock (1926, p. 140) has proved, on the evidence of boles and the absence of chilled margins and metamorphism, that a volcanic episode occurred towards the end of Dinantian times, when basaltic lavas were extruded in the vicinity of Little Wenlock and Lydebrook.

Whereas the evidence is strong to show that Titterstone Clee, and Little Wenlock and Lilleshall received deposits in the Dinantian of different provinces, which may or may not have been in communication (*vide supra*), during part of the Ammanian and the succeeding Morganian these areas became occupied by Coal Measures of a Midland facies (Dixon, E. E. L., in Boulton, W. S., *et al.*, 1933, p. 477). The Ammanian¹ is restricted to the Coalbrookdale field and to the small coalfields of the Clee Hills, where there is a pronounced unconformity. For example, south-eastwards from Little Wenlock, which lies near the western limit of the Coalbrookdale field, more and more of the Dinantian succession, including contemporaneous lavas, has been eroded eventually to disappear between the Lydebrook Dingle and Coalbrookdale itself (Pocock, R. W., *et al.*, 1938, p. 129). Here the Coal Measures rest upon Wenlock Shale, and elsewhere they show contacts with Downtonian, Ludlovian, Valentian, Tremadocian and Lower Cambrian rocks. A similar relationship exists in the Clee Hills where an angular discordance of about 30 degrees is found between the Ammanian and the Cornbrook Sandstone (Visean).

Before the Morganian deposition commenced, the Ammanian rocks were thrown into north-easterly pitching folds, accompanied

¹ The Ammanian corresponds to the Lower Coal Measures and to the lower part of the Middle Coal Measures of Nottinghamshire and Yorkshire (Dix. E. and A. E. Trueman, 1935. 'The value of non-marine lamellibranchs for the correlation of the Upper Carboniferous'. *C. R. 2me Congr. Strat. Carb. Heerlen*, 1, 191).

by faults possessing a similar trend; they were deeply eroded before the sweeping transgression of Morganian times reached the area,¹ and they are now mainly preserved in two synclines named after Dorrington Wood and Madeley (Whitehead, T. H., *et al.*, 1928, p. 51). The Ammanian of Coalbrookdale is famous for the excellently preserved plants and animals which were collected from ironstone nodules;² these have been recorded from several stratigraphical horizons, but probably the Pennystone Ironstone has provided the majority of the specimens. Unfortunately, the ironstone is no longer worked. The zonal position of the Pennystone is suggested by the presence of *Anthracosia aquilina* in higher beds, and as this fossil is indicative of a level well above the base of the *modiolaris* Zone, the Pennystone Ironstone may thus occur in the middle of this zone in a position comparable with that occupied by the Amman marine horizon of South Wales (Trueman, A. E., 1940, p. 40). Mitchell and Stubblefield also arrive at a *modiolaris* age by comparison with the South Staffordshire Coalfield (1945, p. 25). The occurrence of *A. cf. aquilina* in a tip-heap on the hillside above the main Titterstone Clee quarry was announced by Trueman (*in discussion*, Marshall, C. E., 1942, p. 24) who deduced therefrom the presence of strata not higher than the lowest one-third of the *similis-pulchra* Zone; a comparable correlation has recently been made by Trueman and Weir (1946-51, p. 121, pl. 16, fig. 16) on *A. cf. aquilina* collected from an opencast coal trial-trench at Dawley. The *A. aquilina* species-group has a moderately long stratigraphical range, and individual records are frequently difficult to place within that range; hence the difference in age attributed to the forms found in the Pennystone Ironstone and on the Clee Hill. It should be noted that Trueman and Weir (1946-51, pp. 12, 28, 36) specifically mention the occurrence of *Carbonicola bipennis*, *C. rhomboidalis* and *C. browni* in the Coalbrookdale Coalfield, and thus some part of the *communis* Zone, underlying the *modiolaris* Zone, is found there.

Morganian times witnessed the spread of swamp, delta and vegetation over those portions of the land surface which nowadays retain no trace of Carboniferous rocks of an earlier age. Southerly overlap in the Shrewsbury coalfields³ results in the absence at the surface of the Etruria Marl,⁴ but in the lower-lying region of Coalbrookdale, the equivalents of these rocks may be preserved in the lower division of the Coalport Beds. The Newcastle-under-Lyme Group probably corresponds with the higher division of the Coalport Beds, and consists of sandstones and multi-coloured mudstones

¹ This unconformity was originally named the Symon Fault in the Coalbrookdale field.

² The ironstone nodules were the source of the iron used in making the first cast-iron bridge which still stands athwart the River Severn at Ironbridge.

³ Included here are the Hanwood Coalfield, west of Shrewsbury, the Leeboothwood Coalfield, extending part of the way down the Church Stretton valley, and the small outlier of Dryton, near the Wrekin.

⁴ Small outcrops have been mapped at the western extremity of the Hanwood Coalfield (Pocock, R. W., *et al.*, 1938, p. 140 and fig. 25).

TABLE VI. CARBONIFEROUS SUCCESSIONS IN SHROPSHIRE

	Clee Hills	Coalbrookdale ¹	Shrewsbury Coalfields
Morganian	? Absent ²	Enville Beds	Alberbury Breccia } Erbistock Group
		Keele Beds	Keele Beds
		Coalport Beds	Newcastle-under-Lyme Group
Ammanian	Productive Measures ³	Productive Measures ³	Etruria Marl
Namurian	Absent	Absent	Absent
U. Dinantian (Visean)	Cornbrook Sandstone (C ₂ and perhaps higher beds)	Limestones with basalt flow (D ₂) Lydbrook Sandstone (D ₁)	Absent
L. Dinantian (Tournaisian)	Tournaisian Limestones (K-C ₁)	Silurian, Tremadocian or Cambrian	Absent
Upper Old Red Sandstone	Farlow Sandstone		

¹ The Visean of Lilleshall extends down to include the S₂ Subzone.

² Not recorded on map illustrating geological structure of the Bridgnorth district (Whitehead, T. H. and R. W. Pocock, 1947, fig. 13, p. 119) but diagrammatically represented as once having covered the area by Trueman (1947, fig. 2, p. lxxii).

³ The lowest beds of the Coal Measures (*Lenisulcata* Zone) have not been identified.

containing a few thin coals and *Spirorbis* limestones. The Keele Beds are poorly exposed throughout the several coalfields but are predominantly an argillaceous series with interbedded *Spirorbis* limestone and sandstone. Few non-marine lamellibranchs are recorded from the Morganian of the Shrewsbury coalfields; loose material from tip-heaps at Leebotwood have provided *Anthracomya* cf. *calcifera*, *A.* aff. *phillipsi* and *A.* cf. *pringlei* indicative of a high horizon (Dix, E. and A. E. Trueman, 1931, p. 199).

The appearance at the top of the Keele Beds of the Alberbury Breccia, which shows an outcrop restricted by faulting and by the Trias unconformity, is of particular interest; a coarse conglomerate and calcareous sandstone at Pitchford may also belong here. The Breccia, outcropping between Alberbury and Cardeston, is about 250 ft. thick and includes subordinate layers of marl; the breccias themselves are composed of many angular and large pieces (up to 12 in. across) of Carboniferous Limestone, often dolomitised and set in a calcareous matrix containing quartzite-pebbles (Pocock, R. W., *et al.*, 1938, p. 154). Owing to the overlap of Coal Measures to the south and south-east, and to an intervening ridge of pre-Carboniferous rocks, which isolated the Lower Carboniferous outcrops of Coalbrookdale, Wedd (*in* Pocock, R. W., *et al.*, 1938, p. 162) has deduced that the Carboniferous Limestone fragments were formed by the violent denudation of source-rocks situated on the west side of the Shropshire-Cheshire syncline in the district south of Llany-mynech Hill. Derived fossils, preserved in the fragmentary limestone, are not infrequently found; only specimens of *Lonsdaleia* have been noted and these are not distinctive regarding the provenance of the rocks.

The analcite-olivine-dolerite of Titterstone Clee is almost certainly an intrusive rock (Marshall, C. E., 1942, p. 4) and not of volcanic origin as Pocock (1931, p. 4) has claimed. Age-determinations, founded on the helium method, are prone to give minimum values but among themselves they are consistent. When the figures given for the Clee Hill intrusion and the Little Wenlock lava, the latter being of Viséan age, are compared the slight difference between them is in accord with a Coal Measures age for the dolerite (Urry, W. F. and A. Holmes, 1941, p. 51). This result is also supported by the fragments of tachylite occurring in the overlying sedimentary rocks, which clearly prove that the igneous mass was exposed to erosion in Coal Measures times.

8. THE TRIASSIC SYSTEM

The transference of the Alberbury Breccia to the Erbistock Group of the Upper Coal Measures (Pocock, R. W., *et al.*, 1938, p. 122) leaves no rocks obviously acceptable as Permian in age in Shropshire. The Mesozoic deposition is thus introduced by the markedly transgressive Triassic rocks of the Cheshire Basin which, reaching south-

wards to the Shrewsbury region, rest astride the grain of the Lower Palaeozoic and Pre-Cambrian rocks; there is a conformity of outcrop between the Trias and the Coal Measures but a long interval of time separates the formation of these stratal groups. Both the Bunter and Keuper Series are recognised, but neither plays an important rôle in the geology of the southern portion of the county. The Bunter shows a threefold division into Lower and Upper Mottled Sandstone separated by Pebble Beds. The sandstones are usually brick-red in colour, mottled, false-bedded and sometimes carry millet-seed grains. The local basal developments of the Lower Mottled Sandstone may be a conglomerate or a breccia. Pocock (1938, p. 164) records an outlier wherein a breccia, consisting of angular fragments of Uriconian volcanic types and Cambrian quartzite, forms a marginal deposit along the north-west flank of the Wrekin, which was an upland region in the desert landscape of these times. The Pebble Beds are mainly sandstones containing lenticular bands of conglomerates principally composed of quartzite-pebbles, although igneous pebbles have been identified.

The Lower Keuper Sandstones are in most places conformable with, and are an upward gradation of, the Upper Mottled Sandstone. They include, at their base, the yellow sandstones (building-stones) of Grinshill, which are frequently false-bedded, carry ripple-marks and occasionally show the imprints of raindrops; here several skeletons of the reptile *Rhynchosaurus articeps* (Owen), re-described by Huene (1929, p. 40), have been collected. The overlying Waterstones and Keuper Marls call for no comment.

Dykes of a decomposed porphyritic dolerite are recorded from the neighbourhood of Grinshill (Pocock, R. W., 1925, p. 60).

Some of the physiographical features now visible in the ancient rocks of southern Shropshire, may have originated during Triassic times. For example, when viewed from any of the Uriconian hills on the east of the Church Stretton Valley, the Longmynd presents a plateau-like summit which is gently inclined to the north-east. Some have claimed this feature arose in the Valentian epoch, but the behaviour of the Valentian rocks suggests the land surface at that time was one of pronounced and irregular topography; others have attributed the origin to Carboniferous denudation but again the distribution of the Coal Measures points to a varied land surface. Desert conditions are possibly the best under which peneplanation may arise, and the Longmynd plateau may have originated during the interval connoted by the New Red Sandstone, but unfortunately there appears to be but little evidence on which even to surmise.

9. THE GLACIAL HISTORY

The glacial deposits of Shropshire and adjacent counties have been intensively studied of recent years and several authoritative accounts of the geological history are available (Wills, L. J., 1924, 1937, 1948;

Pocock, R. W. and D. A. Wray, 1925, p. 65; Whitehead, T. H., *et al.*, 1928, p. 174; Derryhouse, A. R. and A. A. Miller, 1930, p. 101; Pocock, R. W., *et al.*, 1938, p. 181; Pocock, R. W. and T. H. Whitehead, 1948, p. 25); no more than a brief description of the sequence of events will be attempted here.

The Older Drifts are believed to represent two glacial episodes, each followed by an interglacial episode, but the deposits are patchy because, generally, they have been removed by later glaciers, or by river-action, or they have been incorporated in the Newer Drifts; evidence for the limits of the glacial fronts frequently rests upon no more than isolated erratics.

The Newer Drifts were laid down from one ice-sheet moving towards the south from the Irish Sea area and another moving south-eastwards and eastwards from Wales. The ridge of ground, which at the present day stands astride the River Severn at Ironbridge, was a watershed in pre-glacial times, and the Upper Severn and other systems drained northwards into the Irish Sea. On the south-east side of the divide, the drainage of the Lower Severn was towards the Bristol Channel. The advance of the Irish Sea and Welsh ice prevented the egress of the water to the north and north-east, which became impounded against the watershed to the south-east; it is doubtful whether any evidence remains of these lakes and of their overflow-channels. The eventual retreat of the ice-front led to the re-establishment of lakes, of which first Lake Coalbrookdale and later Lake Buildwas were formed near Ironbridge, and Lake Newport farther to the north-east; a high-level overflow from Lake Coalbrookdale probably started the excavation of the Ironbridge gorge, but this col must later have been re-occupied by ice. Further retreat of the main ice-sheet, which freed the Wrekin District, was accompanied by the coalescence of Lakes Buildwas and Newport, by the water spreading over a greater area and by the production of Lake Lapworth. Melt-waters, derived from the hills to the south-west, finally resulted in the lake-level standing at a height corresponding to the present-day 300-ft. contour, when the water discharged through a col in the watershed, cut the Ironbridge gorge and emptied the lake; thus were the Upper and Lower Severn united, and the main drainage of that river of today initiated. A second advance of the Welsh ice-sheet at about this time threw down detritus upon the sediment left behind by the Irish Sea ice-sheet.

When the ice of the Newer Drifts held the above-mentioned lakes against the watershed, another lake was in existence in the Church Stretton Valley, and was there maintained by a lobe from the main Irish Sea ice-sheet to the north which at one time stood near the present 700-ft. contour in the Church Stretton area. The exodus of lake-water to the south-west was at first prevented by the divide in the valley at Marshbrook, but eventually drainage in that direction, to the Onny Valley and thence to the Teme, occurred and the striking

trench-like valley, commencing near Cwm Head, above Horderley, was excavated. With a subsequent retreat of the ice-front, reverse drainage to the north along the Stretton Valley was again established, and about this time, or perhaps earlier when the drainage was southwards, the marginal overflow-channels on the flank of the Longmynd were cut. The details of this particularly interesting, but minor, part of the glacial history have yet to be elucidated but a preliminary account has been written by Cobbold (1927, pp. 230-4; see also Wills, L. J., 1937, p. 92, fig. 6).

The pre-glacial drainage of the upper reaches of the River Onny probably was southwards across the broad valley at Lydham towards the River Clun. Ice from Clun Forest prevented this southerly flow and the water was diverted eastwards through the Plowden Gap, which is the course maintained by the present-day River Onny. The Severn ice also closed the western entrance to the Lydham Valley; a lake was formed (the lacustrine clays were worked until recently for brick-manufacture near the Roveries), and overflow took place northwards through a marginal channel which later developed into a gorge; this is the Marrington Dingle, situated on the western side of the Shelve Inlier and through which the River Camlad passes. The full force of this 'misfit' drainage can be felt at Church Stoke where, at the southern end of the Marrington Dingle, the river is seen to flow into, and not away from, the hills.

10. GEOLOGICAL STRUCTURE

The dominant structural features of a geological map of south Shropshire are the large number of unconformities, the Church Stretton and Pontesford-Linley lines of disturbance, and the approach to a symmetrical distribution of the older Palaeozoic rocks on the north-west and south-east sides of the Longmynd.

Unconformities, many of a flagrant kind, exist between each System with the exception of the Old Red Sandstone, where no more than a lithological change between the Downtonian and Silurian is recorded; even in the Pre-Cambrian, it has been asserted that the Wentnor 'Series' is unconformable. Further discontinuities have been detected within Systems as, for example, between the Lower and Middle Cambrian, near the base of the Caradoc, under the Farlovian and within the Coal Measures; there are, in addition, several lithological and physical breaks which suggest, if they do not prove, some hiatus in the succession. During much of pre-Cretaceous history, south Shropshire was the site of uneasy crustal stability, but violent orogenic disturbances do not appear often to have affected the region—indeed, recurrent movements, spread over long periods of geological time, are characteristic.

The structure of the Longmynd has not yet been elucidated. Whether the opinion, expressed in earlier pages that these Pre-Cambrian rocks are folded on the grand scale, be acceptable or not,

they have certainly been deformed by at least two periods of earth-movements which were completed before the onset of the Cambrian deposition. The Cambro-Ordovician successions record nothing of a catastrophic nature until near the close of the Ordovician deposition and before the Upper Valentian strata were laid down. The rocks of the Shelve Inlier were now folded, but, more important, they were literally cut into strips by powerful northerly-trending tear-faults which were accompanied by complementary shears running not quite at right-angles to one another and each making an angle usually in excess of 45 degrees with the main tear-faults. The tear-faulting was completed before the Upper Valentian rocks were formed, but in some cases posthumous movements have displaced their unconformable contact. But tear-faulting is not confined to the Shelve Inlier because a similar pattern is present in the Longmynd; the conglomerates of the Wentnor 'Series' and the marker-beds of the Batch Volcanic Group, the Carding Mill Grit and the Buckstone Rock are offset either to the north-east (dextral) or the north-west (sinistral) on the northern sides of the faults, which are certainly tear-faults because they displace strata which are inclined at high angles or are vertical. These relatively unimportant tear-faults are probably connected with large strike- (? tear-) faults which are suspected to define occasionally certain stratal boundaries, viz., east side of the Bridges Group, west side of the Stretton 'Series' at Haughmond (Whitehead, T. H., in Pocock, R. W., *et al.*, 1938, p. 53; and Whitehead, T. H., 1948, p. 182). Also to be included in this group of major tear-faults, is the system separating the Tremadocian from the Pre-Cambrian on the west of the Longmynd, and recent mapping has established minor tear-faulting associated with this important disturbance which mirrors the Church Stretton system farther east. The enigmatical F3 of the Church Stretton fault-zone is vertical and may eventually prove to be a major tear-fault, and in the area mapped by the Geological Survey north of Lawley and on unpublished maps of the Sharpstone-Cwm Head district, F3 is accompanied by other minor faults best explained by their having possessed a pronounced horizontal movement.

The faulting and folding, which south Shropshire sustained about the time connoted by the Ordovician-Silurian boundary, is truly orogenic in character, but they are no more than a portion of the disturbances, which can be identified as nearly contemporaneous in other regions such as Wales and N.W. Ireland, and there are cogent reasons, founded on stratigraphy and palaeontology, for claiming a pre-Silurian and post-Canadian age for many of the movements which affected the N.W. Highlands of Scotland. The orogeny, which attained its climax about the termination of the Ordovician Period, has been considered as part, or the precursor, of the Caledonian Orogeny because it developed out of a geosyncline which is thought to have persisted as a unit throughout the Lower Palaeozoic era; the orogeny

has accordingly been named Eo-Caledonian, but earth-movements, operating over a comparable time-span, are referred to the Taconian Orogeny in North America, and it is this latter name which I have used for the movements which affected the Ordovician and older rocks of Shropshire. The far-flung correlation of the Taconian with the Eo-Caledonian Orogeny is obviously a subject for debate, but they both reached their culmination at about the same geological period.

The Silurian rocks record no history of violent change and, significantly, the Downtonian rocks show no discordance in Shropshire, other than a lithological one, with the Ludlovian. The Caledonian Orogeny, which profoundly affected Silurian and older rocks in Wales, Ireland, the Lake District and southern Scotland, left but little imprint upon Shropshire. Whereas the Caledonian mountains were born from the deeper parts of the Silurian geosyncline, the Downtonian facies represents the waste derived from the erosion of these mountains, and deposition on the south-east flank of the geosyncline was more nearly continuous than in regions situated on the seaward side of that shore. The terrestrial environment of the Old Red Sandstone continued into the Carboniferous, most of south Shropshire being a land-region which was again invaded, but not overrun, by the sea only in late Dinantian times. Further oscillations eventually established conditions necessary to the formation of the Coal Measures, but the incidence of Armorican movements apparently led to no profound re-orientation of the tectonic state of the rocks, and terrestrial conditions again supervened in the New Red Sandstone. During the late Palaeozoic and the Mesozoic eras, south Shropshire thus appears to have acquired a structural stability and, generally considered, the region now suffered no more than gentle warping, sometimes spread over large areas, minor folding and faulting, and recurrent movements along previously established lines of weakness.

The Church Stretton System is a complex comprising numerous faults of which three predominate in their effect and importance (Cobbold, E. S., 1927, p. 565); named from west to east, F1 is a normal fault, which hadees and downthrows to the west, F2 is a thrust fault, which hadees to west but downthrows to the east, and F3 is a vertical fault of unknown character which is here suggested to be a tear-fault. The amount of throw of either F2 or F3 is exceedingly difficult to measure and no reliable value is available. Regarding F1, which displaces Triassic rocks, a figure of as much as 6000 ft. has been calculated, but the throw virtually cannot be determined in a region where facies-changes and unconformities dominate the geological setting, unless members of a conformable series, and of like facies, are in juxtaposition. These conditions are satisfied near New House, Marshbrook, where the downthrow of F1 has been measured at about 600 ft. to the west (Whittard, W. F., 1932, p. 883).

The trend of the Church Stretton fault-belt may divide facies; not infrequently it delimits the western extremity of shelf-seas of various periods, and it separates regions of great unconformity from those where the unconformities may be less powerful or non-existent. These three phenomena, which are so intimately linked with the fault-belt, make it necessary to postulate that the initiation of this line of crustal weakness goes back far into geological history, at least to the beginning of the Ordovician period and probably earlier. Evidence has been adduced to show that, in the area south of Craven Arms, the Aymestry Limestone was formed in a shelf-sea whose westerly margin was a slope descending into deeper water trending parallel to the fault-zone; that, immediately to the east of the faults in the Marshbrook-Horderley Valley, the Wenlockian strata belong to a calcareous facies whereas to the west graptolitic beds occur; that, on the east of the faults, Caradoc rocks of shelf-sea facies are the sole representatives of the Ordovician, whereas to the west an extensive succession from Arenig to Caradoc Series, comprising mixed facies and containing very few physical breaks, is developed in the Shelve area; that the Cambrian rocks are distributed to the east of the faults and, to the west, the only known record is of glauconitic sandstone, presumably, but not certainly, of Cambrian age, found in the Cruckmeole boring near Hanwood; that the Stretton 'Series' crops out only to the west of F2. There were periods when this important structural line was not clearly reflected in the sedimentation, as, for example, during the Tremadocian, the Upper Valentian, the Coal Measures and the Trias depositions. The Church Stretton fault-zone thus 'forms the boundary between a yielding area and a rigid area' (Jones, O. T., 1927, p. 10). A gravity-survey has classified south Shropshire as a region of positive anomaly sometimes exceeding 10 milligals, but a single traverse across the fault-zone at the latitude of Church Stretton does not show a sympathetic change in gravity as might be expected; on the contrary, a gradual increase in gravity-anomaly has been recorded westwards over the faulted region (Cook, A. H. and H. I. S. Thirlaway, 1950, p. 43).

Allusion has already been made to the Pontesford-Linley line of tear-faulting which does not bring many rocks of different ages into contact, though it does exclude at the surface all Cambrian strata, the Tremadocian on the west lying adjacent either to Uriconian or to Longmyndian on the east. The anomalous behaviour of the Caradoc unconformity is of interest because it crosses the Longmynd from the Caradoc area and is exposed in the Pontesbury (Habberley) Brook (see p. 161), but immediately west of the Pontesford-Linley tear-fault the full Ordovician succession from the Arenig to the Caradoc of the Shelve Inlier is met. The Pontesford-Linley fault-line appears to have been associated with a scarp or some other physiographical barrier, not dissimilar to that formed by the Church Stretton fault, which was first crossed by the Ordovician

sea from the west only in *multidens*-times. In the extreme south, about one-sixth mile south-south-east of Lower Bent, a small and unrecorded outcrop of Upper Valentian fine-grained sandstones, charged with *Stricklandia lens*, is presumed to be faulted against Tremadocian and rests unconformably on Uriconian lavas; its preservation is attributed to posthumous movement along the previously-formed main fault.

A third fault-zone, subparallel to the Church Stretton and Pontesford-Linley Systems, has been predicted by Watts (1925, pp. 323, 343) running under alluvium and named the Severn Fault. The need for such a fault has been recognised by other workers (Whittard, W. F., 1932, p. 891; Wedd, C. B., 1932a, p. 12; Whittington, H. B., 1938c, p. 440), because the differences in the stratigraphy of the Ordovician and Silurian rocks on the east and west of such a line are almost as great as those already mentioned between the rocks on opposite sides of the Church Stretton disturbance.

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In the preparation of this survey of the geology of southern Shropshire, I have drawn freely on the work of other investigators; acknowledgment of the source of information is usually given in the text, but some inadvertent omissions of references are only too prone to occur, and for these I offer my apologies to the authors concerned. Dr. C. J. Stubblefield has scrutinised the list of references and Dr. S. Simpson has read and criticised the manuscript; to both I tender my thanks for their generous help. The company of personal friends and of many students has often been the spur to further effort, but my lasting obligation lies with Watts and with Cobbold whose memory and example are to me, as to not a few others, a real and constant inspiration.

NOTES ON THE RELATIONSHIP OF THE URICONIAN AND LONGMYNDIAN ROCKS NEAR LINLEY, SHROPSHIRE

By J. H. James, B.Sc., F.G.S.

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ABSTRACT.—Graded-bedding within the Wentnor 'Series' shows the sequence to be inverted in the Linley area, and the superposition of the inverted Uriconian on different beds of the Wentnor 'Series', is attributed to an unconformable, and not to a faulted, relationship.

NEW evidence concerning the relationship between the Wentnor 'Series', or Western Longmyndian, and the Western Uriconian was found while carrying out field-mapping in the Linley area, and may add to the understanding of the structure and succession of the Pre-Cambrian rocks of Shropshire.

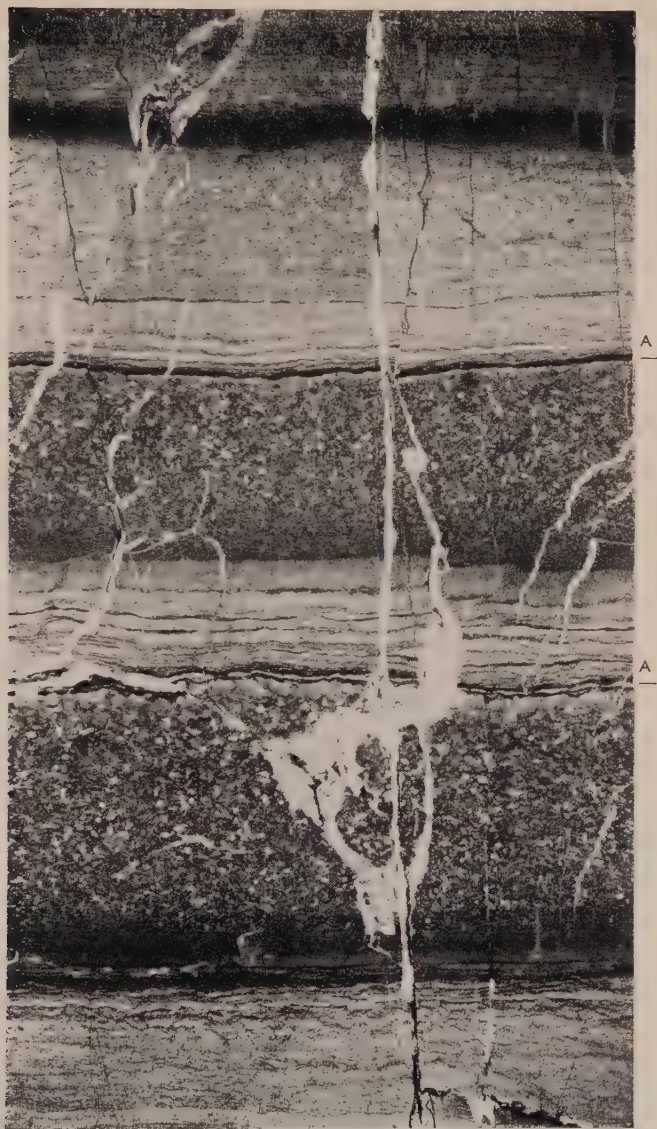
The Wentnor 'Series' of the Linley area, unlike the extreme northern exposures, has a prevailing dip to the west of between 35–45 degrees; the lithology includes conglomerates, grits, siltstones, shales and fine tuffs. The Uriconian rocks show a wide variety of devitrified rhyolites and fine-grained devitrified tuffs, with some basic intrusions.

In two localities, Chittol and Linley Big Wood, the Uriconian and Wentnor 'Series' are found in close proximity. At Chittol, near a quarry situated about 1000 ft. to the west of Beach Farm, green tuffs, belonging to the Wentnor 'Series', were exposed in a trial-excavation and the following sequence was determined:

Sub-soil	...	...	...	...	Thickness		Total Thickness	
					ft.	in.	ft.	in.
					0	2	0	2
URICONIAN								
Brecciated acid lava with vesicles infilled with silica (chalcedonic?): some flow-structure visible. Crystallisation partly original but mainly due to devitrification ...					3	0	3	2
WENTNOR 'SERIES'								
Colour-banded green tuff ...					0	3	3	5
Green tuff, showing graded-bedding ...					0	9+	4	2+

The beds dip to the west, and towards the main mass of the Uriconian, at 46 degrees. Graded-bedding can be seen within the tuffs both in the hand-specimen and thin-section. The graded bands are from $\frac{1}{4}$ – $\frac{1}{2}$ in. thick and the grain-size varies from siltstone to clay. So clearly do the crystal-fragments merge into the fine ash that the direction of grading is at once obvious. In these bands, the coarse material is above and grades downwards into the finer, and hence

TECTONIC TOP



STRATIGRAPHICAL TOP
GRADED-BEDDING IN TUFFS OF WENTNOR 'SERIES', CHITTOL

[To face p. 198.]

grading is here inverted (see Plate 7). In the same bed, the effect of crystal-fragments, dropped upon the unconsolidated fine ash, can be seen. The direction in which the surface of the ash is depressed can also be used as a top and bottom criterion, and this also shows an inversion of the normal order.

To the north of Lower Beach Cottage and occupying the southern part of Chittol Wood, there is a large outcrop of typical conglomerate of the Wentnor 'Series'. This outcrop is associated with green tuffs and displays grading of the pebbles. The largest pebbles, up to 5 in. across, occur on the western side, that is, at the tectonic top since the bed is dipping to the west at 45 degrees; here again there is a suggestion of an inversion of the normal succession, but the evidence is not so conclusive as in the case of the graded-bedded tuffs.

The banded tuffs of Chittol are thus claimed to be inverted. Not only are the tuffs inverted but the conglomerates, grits, siltstones and shales, with which they are associated, are in a similar condition; no evidence has been detected which suggests that the tuffs are a separate formation; in fact, they can be shown to be one bed within a conformable series of Longmyndian rocks.

Exposures of Uriconian acid flows were found immediately above the tuffs some 20 ft. to the west of Chittol Quarry. The excavation, which was dug across the junction of the green shaly tuffs of the Wentnor 'Series' and the Uriconian lavas, showed no evidence of a faulted contact. The Uriconian is lying above the Wentnor 'Series'; the contact is inclined to the north-west at 26 degrees, and there is an angular discordance of about ten degrees with the dip of the Wentnor 'Series' below. Not only is there a discordance in the dip and strike, but in a distance of 600 ft. the inverted Uriconian rests against different beds of the Wentnor 'Series'. In the absence of a faulted relationship, an unconformable contact appears to be proved.

The area of Linley Big Wood, concerned in this paper, is that termed the Knolls, reaching from Coppice Dingle east to Linley Drive. The higher ground is occupied by Uriconian rock while, generally, the lower slopes are composed of the Wentnor 'Series'. In the south-east corner of the wood, Uriconian outcrops again, the east-west repetition being due to a roughly north-south tear-fault. In this area, the strata of the Wentnor 'Series' are similar to those exposed at Chittol. Again they are westerly-dipping towards the main mass of Uriconian and show graded-bedding, which, although not so clearly defined as in Chittol Quarry, still indicates an inversion of the strata.

If the underlying Longmyndian tuffs are proved on graded-bedding to be inverted, the overlying Uriconian must also be; thus the Western Uriconian rocks are older than the Wentnor 'Series'; this confirms Mr. Whitehead's opinion regarding the age-relationship of these rocks in the north-western area of the Longmynd (Pocock, R. W., *et al.*, 1938, p. 12).

EXPLANATION OF PLATE

Photograph of a thin-section showing graded-bedding within the tuffs of the Wentnor 'Series' of Chittol. At points (A) each series of graded beds commences. Since the gradation is from coarse to fine-grained downwards, the stratigraphical top is at the bottom of the photograph, and the section is thus inverted. $\times 5$.

REFERENCE

POCOCK, R. W., T. H. WHITEHEAD, C. B. WEDD and T. ROBERTSON. 1938. Shrewsbury District, including the Hanwood Coalfield (One-inch Geological Sheet 152 New Series), *Mem. Geol. Survey Gt. Brit.*, London, 1-297.

THE LUDLOW ROCKS NORTH OF CRAVEN ARMS

By J. Shirley, D.Sc., F.G.S.

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ABSTRACT.—A review of previous work shows that the Aymestry Limestone may be defined as the calcareous development of the middle part of the Ludlow formation from the Severn Valley to south of Aymestry. It includes the shell banks of *Conchidium knighti* at Weo Edge and the *Dayia* Shales, both of which are restricted in geographical range. Detailed collecting indicates the possibility of correlation with the sequence established at Builth (Straw, S. H., 1937). Sections through the Aymestry Limestone and the passage into the Upper Ludlow, where the *Chonetoides grayi*-fauna is developed, are described.

THE Aymestry Limestone was first noticed as a separate formation by Murchison (1839, pp. 201–4). He drew particular attention to the outcrop stretching from Aymestry northward to Norton Camp, and implied that *Pentamerus* [*Conchidium*] *knighti* is characteristic throughout this length, though not always so abundant as at Weo Edge which he specially mentioned. He clearly did not mean to exclude the ridge of limestone continuing farther north to the Severn Valley, although he says of the Dinchope area ‘it appears . . . the *Pentamerus knighti* does not occur here’ and he illustrated the Aymestry Limestone on his section through the Yeld some miles farther north. The Aymestry Limestone may legitimately be defined as the calcareous development of the middle part of the Ludlow formation and this stretches from the Severn Valley to south of Aymestry where it dies out. Murchison also included in the Limestone the more or less calcareous beds with abundant *Dayia navicula* which overlie the Limestone in the area south of Norton Camp. Elles and Slater (1906) include, in the Aymestry Group, the *Conchidium knighti* Limestone and the *Dayia* (Mocktree) Shales on the grounds that the brachiopod-fauna is more closely allied to that of the Aymestry Limestone than to that of the higher calcareous beds; and, in addition, *Monograptus leintwardinensis*, which certainly occurs in the Aymestry Limestone, is also found in the highest beds of the Mocktree Shales. They did not study the group farther north than Norton Camp. On the other hand, Alexander (1936) suggested that it might be convenient to draw the base of the Upper Ludlow at the base of the Mocktree Shales, where she had detected signs of a stratigraphical break. This question is complicated by our existing ignorance of the exact ranges of the individual members of the shelly faunas of these strata and by the curiously restricted geographical distribution of certain of them, of which *Conchidium knighti* is the best example. For the moment it is probably more convenient to

regard the Mocktree Shales as part of the Aymestry Group and define this as the group of calcareous beds in the middle part of the Ludlow formation between the Whitcliffe Flags, or their equivalents, above, and the Lower Ludlow Shales below. Generally, these beds are calcareous from about Aymestry northward to the Severn Valley, sometimes forming fairly pure limestones, but more often they are an alternation of nodular limestone-bands and mudstones. The passage upward, from the Lower Ludlow Shales, is gradual, the calcareous nodules becoming more frequent until they form an impure limestone. The upper limit is generally better defined by the rapid passage into the Upper Ludlow Flags and the dominance of the *Chonetes striatellus*-fauna.

Since the original account by Murchison, little was written on the Aymestry Group until the study by Elles and Slater (1906) who described the group in the neighbourhood of Ludlow, Weo Edge and Norton Camp. The next account is that by Robertson (1927), working mainly in the Wenlock area. Here *C. knighti* is absent and the *Dayia* Shales are not developed. The Aymestry Group is about 80 to 100 ft. thick and Robertson recognised an upper zone with very common *Sphaerirhynchia* [*Wilsonia*] *wilsoni*, a middle zone with abundant *Gypidula bravonium* Alexander [= *Sieberella galeata* auctt.] and a lower zone in which *Strophonella euglypha* is given as the most common fossil. In a rapid survey of the higher Silurian rocks southward to Norton Camp, he states that from this point (i.e., two quarries in the valley immediately north of Norton Camp) to Wenlock 'it can be said that *C. knighti* has not been recorded and that the *Dayia navicula* zone is almost non-existent' (Robertson, T., 1927, p. 95). He also states that the Aymestry Group has a constant thickness of about 80 to 100 ft. from Linley and Willey, as far as Corvedale, and to within a mile or so of Norton Camp. The description of the Aymestry Group is repeated in the memoir on the country between Wolverhampton and Oakengates (1928, pp. 20-3). In 1932, Das Gupta summarised his work on the graptolite-faunas of the Long Mountain and Wenlock Edge. From Norton Camp northward to Millichope, he placed the Aymestry Limestone within the zone of *M. leintwardinensis*, which is said to occur below the limestone in 'grey earthy calcareous flags with irregular bands of thick generally nodular limestones'; also 'at all these localities [i.e., at Dinchope, Siefert Batch and Delbury Batch] *M. leintwardinensis* has been found occasionally throughout these beds while one specimen found in the highest beds near Millichope may be referred to *M. leintwardinensis* var. *incipiens* Wood' (Das Gupta, T., 1932, p. 353). He remarks further (pp. 354-5) 'it is probable however that the limestones of the Aymestry Group while being developed as thinner beds in that country [from Norton to Munslow] may belong in part to a slightly higher horizon and is directly overlain by the flagstones of the Upper Ludlow Group'. Since Das Gupta gives no local details of his

collecting-points in this area, it is difficult to gather where he draws the limits of the Aymestry Group, particularly as he believed that 'the mass of limestone seen at Norton Camp rapidly breaks up to the north-east through its change to nodular beds with intercalations of mudstone flags, especially in the lower portion' (p. 353).

Mrs. Alexander (1936) mapped the outcrop of the Lower Ludlow rocks including the Aymestry Limestone and the Mocktree Shales from Aymestry northward to Dinchope, and, in a series of papers, she has redescribed certain members of the fauna. She adduced evidence to show that the base of the Aymestry Limestone reaches down into the *M. tumescens* Zone in that part of the outcrop from Norton Camp to south of Leintwardine, rising into the *M. leintwardinensis* Zone to the north and south of this area in which the Limestone is also said to reach its greatest thickness.

The present writer began detailed work on the Ludlow rocks many years ago, principally in the Munslow and Craven Arms area, but it has been subjected to long interruptions by other necessary work and, therefore, the following account should only be regarded as a summary of views developed so far, and is subject to modification as further progress is made. The object of the work was to subdivide these rocks according to their shelly faunas and compare the ranges of the fossils with those in the contemporary rocks of different facies in the Builth area. In my opinion, any subdivision of these rocks, apart from lithological divisions, must be compared with those established at Builth by Straw (1937). He found that, throughout the thickness of 4000 ft. of mudstones and shales covered by the *Dayia navicula*- and *Chonetes striatellus*-faunas, there are variations 'due partly to the continual process of replacement of relatively short-ranged species by others which are, in turn, superseded, but chiefly to the sudden expansion in numbers of different species at different levels. The latter species are not as a rule confined to the horizon of their maximum. They are usually present though not common at lower horizons and may persist for a time in diminishing numbers after the local acme' (Straw, S. H., 1937, p. 411). The same may be said of the Shropshire succession but with the added difficulties that the facies is more calcareous, the succession comparatively condensed and continuous sections are rare. The change in facies is reflected in the presence of such well-known forms as *C. knighti* and *Strophonella euglypha* which are absent at Builth. It appears, too, that, in order to make proper comparisons, it is necessary to study the shelly faunas of the whole of the Ludlow succession and not to confine oneself to the study of one set of beds only, and also to collect from each stratum—a slow task! The Lower Ludlow Shales contain a shelly fauna which is directly ancestral to and continues into that of the Aymestry Group. The difficulties of making zonal divisions, based on the continuously changing shelly fauna, are exactly those which confronted Dr. Straw at Builth and the solution is the same: we must

depend on the succession of local acmes of different species and these may not necessarily be at the same horizons as in the predominantly mudstone succession at Builth, but already sufficient resemblance is appearing to make it hopeful that a complete correlation will eventually be possible.

The incoming of the distinctive Upper Ludlow fauna makes a fairly definite horizon both in Shropshire and at Builth. There seems, at least in the Munslow area, to be no sharp break in the strata but the typical members of the Upper Ludlow fauna enter one by one and become rapidly established. There is, therefore, a slight overlap of the ranges of certain distinctive members of both faunas and this provides a valuable datum-line for comparison especially as it contains certain elements which are confined, or almost confined, to this horizon. This disappearance of the fauna of the upper part of the Aymestry Group and its replacement by the Upper Ludlow fauna, can be conveniently demonstrated in the small quarries at the side of the road about a mile north-west of Diddlebury. The more northerly of the quarries shows about 40 ft. of nodular impure limestones becoming sandy and flaggy towards the top. The main body of the quarry provides a brachiopod-association characteristic of the upper part of the Aymestry Group of this area—*Sphaerirhynchia* [*Wilsonia*] *wilsoni*, *Camarotoechia nucula*, *Atrypa reticularis* probably var. *sedgwicki*, *Whitfieldella canalis*, *Dayia navicula*, *Stropheodonta filosa*, *Chonetes minimus*, *Dalmanella orbicularis*, *Lingula lewisi* and *Monograptus leintwardinensis*. In the uppermost beds of this quarry and the more southerly of the two quarries, *S. wilsoni*, *W. canalis* and *L. lewisi* have not been found but all the others are present together with *Chonetoidea grayi*, *Calymene* sp., *Encrinurus* cf. *punctatus*, *Proetus* sp., *Bellerophon* sp., *Murchisonia* sp. and *Dalmanella lunata*. The earliest specimens of *D. lunata* are small and directly associated with *D. orbicularis* but already in the upper beds of the southerly quarry, they are more common and larger. On some bedding-planes in the flags, *M. leintwardinensis* is frequent. This association can be compared very closely with that of the *Chonetoidea grayi* Beds of Builth. The next quarry, about 250 yds. to the south-east at the junction with the road which descends to Fernhall Mill, shows the typical Upper Ludlow association of *Chonetes striatellus*, *C. nucula*, *D. lunata*, *Modiolopsis complanata*, *Beyrichia torosa* and *Serpulites longissimus*. The characteristic Aymestry fauna has disappeared. From this point, these beds persist down the dip-slope to the junction with the main road to Ludlow.

The Lower Ludlow shales are not generally well-exposed since they weather into the broad Hope Valley between the edges formed by the Wenlock and Aymestry Limestones. Small stream-bank exposures in the lower part of the shales are not infrequent and these provide *Dalmanites* cf. *vulgaris* (= *caudatus* auctt.), *Phacops* sp., *Acidaspis* sp., a small *Eospirifer*, *Nucleospira* sp. and, occasionally,

C. grayi. The last named reappears at the top of the Aymestry Group and this repetition is similar to that at Builth. The best section in the Lower Ludlow is that alongside the stream north-west of Upper Millichope. The shales provide numerous *Monograptus tumescens*, *D. cf. vulgaris*, small smooth spiriferids and fairly numerous *D. navicula* which has a similar range to that at Builth, where it occurs from the *M. nilssoni* Zone into the basal beds of the Upper Ludlow. In this latter area, however, it never occurs in such numbers as in the Mocktree Shales. The upper part of the Ludlow Shales are hardly exposed for the 500 yds. east of Upper Millichope, and the small quarry opposite the lodge entrance to Millichope Park is in the lower beds of the Aymestry Group, which here seem to expand into a series of calcareous nodular beds forming more than one scarp-feature considerably thicker than the 100 ft. suggested by Robertson (1927). This quarry provides *S. euglypha*, *A. reticularis*, *Favosites* sp. and Bryozoa, and one specimen of *Leptaenisca* sp. has been found. This genus has not been previously recorded from British rocks. The upper beds of the group are exposed in the small quarry 350 yds. north of Holloway Farm at Hungerford. This provides *M. leintwardinensis*, *A. reticularis*, *S. wilsoni*, *C. nucula*, *D. navicula*, *S. filosa*, and, less commonly, *C. striatellus*, *Delthyris* sp., *D. lunata*, *Murchisonia* sp., *Tentaculites* sp. and *Proetus* sp. This quarry is at the horizon of the change from the Aymestry Group to the Upper Ludlow. About half a mile along the road north-east from Hungerford, a quarry opposite Broadstone Farm exposes about 35 ft. of calcareous flags with a typical Upper Ludlow association, together with occasional *D. navicula* and *Cardiola interrupta*, the highest occurrence of these forms. These beds are in the lower part of the Upper Ludlow which contains the same fauna throughout, consisting of few species and large numbers of individuals.

Returning to the area south of Diddlebury, the section along Siefton Batch is interesting. A small quarry on the south-west side of the road, 500 yds. south-east of Hillend Farm, provides *Gypidula bravonium*, *S. euglypha*, *C. cf. nucula* and small corals with an occasional *C. knighti*. This is the northernmost point at which *Conchidium* is known to the writer. The exposure is not far above the base of the Aymestry Limestone feature and seems to be in the lower part of that formation. About 350 yds. along the road to the south-east, is a quarry which contains *A. reticularis*, *S. wilsoni*, *C. nucula*, *D. orbicularis*, *D. lunata* (small form) and rare *D. navicula*, and, in the lane a short distance further, the same fauna with *M. leintwardinensis* is found. These beds are evidently in the uppermost part of the Aymestry Group and dip-measurements suggest that they are about 150 ft. above the exposure with *C. knighti*. The next exposure, about 200 yds. farther, provides the typical Upper Ludlow fauna. From this area southward, the development of limestone becomes more important and *C. knighti* occurs more frequently, but it is not

distributed uniformly, being common in some beds and rare or absent in others. The upper 12 ft., in the quarry near View Edge Farm, contains *A. reticularis* commonly and other shells, including *D. navicula*, but *C. knighti* appears to be absent. Below this is 6 ft. of limestone crowded with *C. knighti* and then about 9 ft. with only rare specimens. *Dayia navicula* also occurs well below the *Conchidium* Beds at Stokewood Cottage (Shirley, J., 1939) in an association which suggests comparison with the upper part of the *Cyrtoceras* Mudstones of the Builth succession.

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NOTES ON THE OLD RED SANDSTONE OF THE CLEE HILLS

By H. W. Ball, B.Sc., Ph.D., F.G.S., and D. L. Dineley, B.Sc., Ph.D.,
F.G.S.

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ABSTRACT.—The stratigraphy of the Old Red Sandstone of the Clee Hills is described, and a brief account of the palaeontology is given. Within the Lower Old Red Sandstone, the subdivisions Downton Series, Ditton Series and Clee Series are recognised. The Clee Series rest conformably on the Ditton Series, and may be equivalent in part to the Senni Beds. The Upper Old Red Sandstone is represented by the Farlow Sandstones Series.

INTRODUCTION

THE following notes refer to the outcrop of Old Red Sandstone lying between Corvedale, the Wyre Forest Coalfield and the Teme Valley, a compact geographical region dominated by the Brown Clee and the Titterstone Clee Hills.

During the Geologists' Association's excursion to the area in 1925, W. W. King acted as local director and published a short account of the Old Red Sandstone succession in the PROCEEDINGS of that year. Recently, a rather different classification of the strata has been suggested by White (1950).

As King (1925) pointed out, the geology of the area is largely reflected in the physiography. The low-lying wide valleys of the River Corve, the Mor Brook, the Ledwyche Brook and the River Teme are incised along the outcrops of the soft Downtonian marls (see Fig. 1). The '*Psammosteus* Limestone' escarpment, a sharp rise of about 200 ft., and the platform behind it, are formed by the relatively hard sandstone-cornstone succession of the Dittonian. These features are, perhaps, developed best to the north, west and south-west of the Brown Clee Hill. Above this platform of Dittonian beds rises the main mass of Brown Clee Hill, consisting of beds of post-Dittonian age, unconformably overlain by two small outliers of Coal Measures. Between Cleeton, Farlow and Walton, the escarpment of the Farlow Sandstones and the lowest Carboniferous rocks forms a prominent east-west feature. To the south, the main outcrop of the Carboniferous gives rise to a high, level platform and caps Titterstone Clee Hill.

There has been some controversy as to where the base of the Old Red Sandstone should be drawn. Some authorities (Stamp, L. D., 1923; Robertson, T., 1926; Straw, S. H., 1929) have regarded the Ludlow Bone Bed as the lowest part of the Old Red Sandstone, but King (1934) placed the upper limit of the Silurian some 2750 ft. higher in the succession.

Pocock (Whitehead, T. H. and R. W. Pocock, 1947) described

the north-eastern part of this area in the memoir to Sheet 167 (Dudley and Bridgnorth) of the Geological Survey, and here he introduced the names Downton Series and Ditton Series, placing the former in the Silurian. This, and the classifications suggested by previous workers, has been criticised by White (1950) in his detailed study of the question of the lower boundary of the Old Red Sandstone. Carefully weighing the palaeontological evidence, White suggests that the Ludlow Bone Bed should be taken as the basal member of the Old Red Sandstone System.

The present authors accept this view, and have retained Pocock's terms 'Downton Series' and 'Ditton Series' with but little modification.

THE STRATIGRAPHICAL SUCCESSION¹

2. Upper Old Red Sandstone

- (d) *Farlovian: Farlow Sandstones Series*—A series of yellow, grey and brown sandstones with bands of purple and green marl about 400 ft.

1. Lower Old Red Sandstone

- (c) *Post-Dittonian: Clee Series*—Principally buff, grey, purple and brown sandstones, with marl and pellet bands... about 900 ft.
 (b) *Dittonian: Ditton Series*—An upper group of coarse and fine sandstones and pellet cornstones, with thick red and green marls with race, grading downwards into a lower group of fine red and green sandstones and cornstones in thick red and green marls with race; with '*Psammosteus*' Limestones at the base 1000–1200 ft.
 (a) *Downtonian: Downton Series*—
 (ii) *Red Downton Formation*; an upper group of thick red marls with thin sandstones and cornstones near the top ... 250–400 ft.
 '*Holdgate Sandstones*.' Thin local purple and green micaceous sandstones, intercalated with marls ... 0–400 ft.
 A lower group of marls with thin lenticular sandstones at the base... 350–400 ft.
 (i) *Grey Downton Formation*; grey, green, olive and buff-coloured lenticular sandstones and siltstones, often calcareous, with purple and grey shaly marls. Ludlow Bone Bed at the base... 15–170 ft.

DESCRIPTION OF THE BEDS

1. The Lower Old Red Sandstone

- (a) *Downtonian: Downton Series*—(i) *The Grey Downton Formation*

The lowest Downtonian beds appear to rest conformably on the marine Ludlovian and to present a passage facies between the Ludlovian below and the red beds above. Elles and Slater (1906) have described the stratigraphy of this group (their Downton Castle or

¹ The classification given here is different from that attributed to H.W.B. by Professor L. J. Wills in the second edition of his *The Palaeogeography of the Midlands* (1950), this being due to a misunderstanding of the stratigraphical significance of the forms previously referred to *Rhinopteraspis* cf. *duncensis* but now attributed to *Rhinopteraspis* cf. *leachi*. The term 'Wheathill Beds', quoted from the same source, is a local name erected merely for convenience during the mapping of the area, to cover the upper part of the Ditton Series containing the *leachi*-fauna. As such, it is given no stratigraphical significance at present. For uniformity, 'Clee Series' is substituted for the term 'Clee Beds'.

Yellow Sandstones and Temeside or *Eurypterus* Shales) in the Ludlow district.

Exposures are few, but in Corvedale, some six miles to the north of Ludlow, mapping shows that the Grey Downton Formation is of variable thickness (Dineley, D. L., 1951, p. 132). The group is characterised by grey-green and olive clays or shales with thin, olive, flaggy and micaceous sandstones and pellet-bands.

(ii) *The Red Downton Formation*

The grey facies rapidly gives way to a thick monotonous succession of red, green-spotted marls. Near the base of the division, thin sandy and pellety beds sometimes exist, as in western Corvedale, and may represent the Ledbury Beds, though no fauna has been obtained from them.

This part of the Old Red Sandstone sequence is very poorly exposed, the Fishmore Brick Pit at Ludlow giving the best section in the district. Here marls, low in the sequence, are accompanied by thin, flaggy, green and red sandstones and lenses of water-sorted marl-pellets and race-nodules. These beds are frequently cross-bedded and strong current-action is indicated. One of the sandstones has revealed traces of sun-crack markings.

King's group I3 (1934), the Holdgate Sandstones, can be traced in mid-Corvedale from near Sutton to Stanton Long, where they occur as thin-bedded lenses of pink-brown sandstones some 400 ft. above the Ludlow Bone Bed. At Baucott, about 13 ft. of these sandstones are present. To the north and in the neighbourhood of Acton Round, the sandstone-lenses increase in number until almost 400 ft. of strata are occupied by them. The highest sandstone bed appears to be 250 ft. below the '*Psammosteus*' Limestones at Monkhopton. Often the marls within the group are sculptured by erosion surfaces, and the sandstones show current-bedding at almost every exposure. The exact height of the lowest Holdgate Sandstone above the Ludlow Bone Bed in the north, is not known, for the solid geology is obscured by drift. Mr. D. W. Gossage reports (*in litt.*) that similar beds are developed some 400 ft. below the '*Psammosteus*' Limestones to the south of Cleobury Mortimer.

Near the top of the red marl sequence, sandstones and cornstone-lenses are locally present occupying a thickness of as much as 100 ft. below the '*Psammosteus*' Limestones; they are similar in lithology to those of the Ditton Series above. It is with the recognition of the faunal sequence within these beds that the suggestion of a revised base to the Dittonian has been made (White, E. I. and H. A. Toombs, 1948; White, E. I., 1950).

(b) *Dittonian: Ditton Series*

King's '*Psammosteus*' Limestones phase is marked by the appearance of limestones 'in solid or nodular bands 1 inch to 12 ft. thick,

and embedded in fine light purple brown calcareous sandstones and green and red marls' (King, W. W., 1925, p. 383). The beds outcrop along the escarpment below the main platform of the Dittonian rocks. In the area about Brown Clee Hill, one limestone band may be developed to a greater thickness than the others. It appears to be nearly continuous, although it is extremely irregular in thickness. Usually the bed is massive above, grading downwards into rubbly and nodular material, and having an average thickness of 6 ft. Locally the limestone passes laterally into red nodular marl, but, within the space of a few feet, may return to its former thick development. Throughout much of the area, this main '*Psammosteus*' Limestone appears at the very base of the sandstone-cornstone sequence, with occasional thinner limestone bands and lenses a few feet higher up. White (1950) has suggested that the '*Psammosteus*' Limestones may be diachronic, but here the division between the Downtonian and the Dittonian rocks of the district may be conveniently drawn at the base of this main '*Psammosteus*' Limestone. D.L.D.

The great thickness of alternating marls, sandstones and cornstones above the '*Psammosteus*' Limestones gives rise to the prominent platform to the north, west and south-west of Brown Clee Hill. Thus, within the Ditton Series, are incorporated all the strata lying above and including the '*Psammosteus*' Limestones, and below the limestone marking the base of the Clee Series. Marls still occupy the major part of the succession, but lenticular, often false-bedded, red, purple, green and brown sandstones and cornstones are present in great numbers. This is particularly so near the base and towards the top of the series; several hundred feet of the middle part of the subdivision appear to be rather barren of these coarser-grade rocks.

The marls are identical with those of the Downton Series below, but green silty bands are frequent; race is common in many of the marls. The sandstones, locally with marl-pellet or basal cornstone layers, often rest on erosion-surfaces in these marls. Thin limestones may be developed from place to place, and many of the arenaceous beds themselves are markedly calcareous.

Ripple-marks, sun-crack markings and supposed animal-trails have been found associated with many of the sandstones.

Towards the top of the sequence, the Ditton Series becomes progressively coarser in grade, and duller in colour, resembling the overlying Clee Series.

The Ditton Series has an estimated thickness of between 1000 and 1200 ft. in the area to the north and west of Brown Clee Hill.

The fauna of the Dittonian strata is of great importance, yet its mode of occurrence renders collecting and tentative zoning difficult. The fossils are rare, occurring in isolated pockets and lenses within the sandstones and cornstones; often such lenses yield a rich assem-

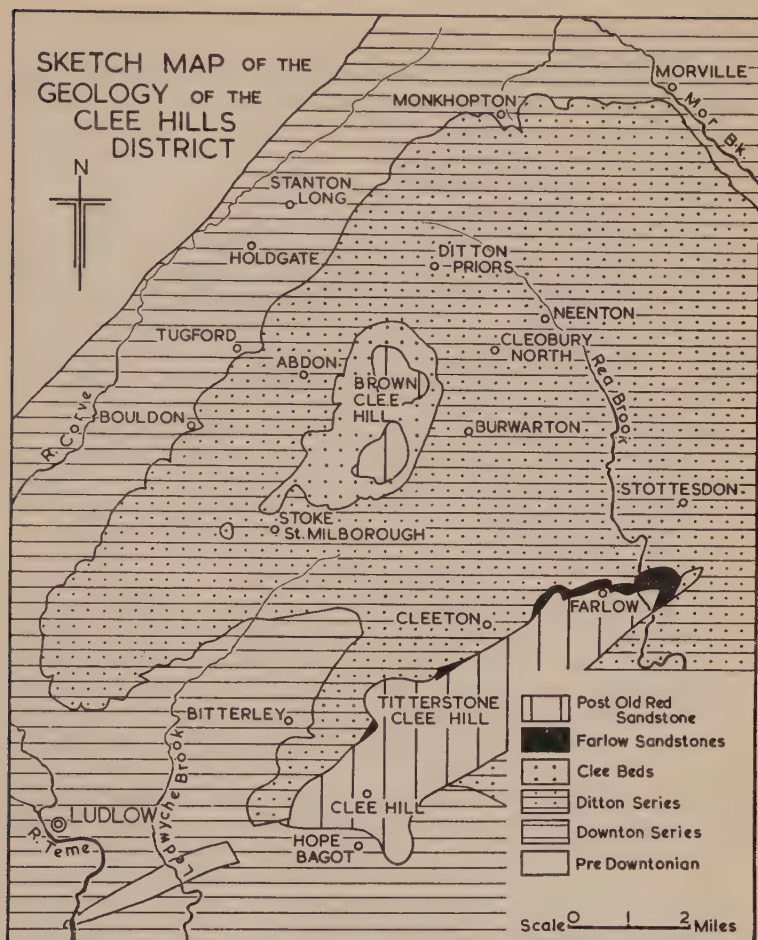


FIG. 1.—A generalised map of the Old Red Sandstone of the Clee Hills.

blage of ostracoderm fragments. The fauna of the Ditton Series is listed below.

(c) *Post-Dittonian: Clee Series*

The major part of Brown Clee Hill itself is composed of beds of post-Dittonian age, here named the Clee Series, consisting of some 900 ft. of principally grey, buff and brown gritty sandstones, with intercalated marl-bands. The beds have yielded no indigenous fauna, but can be broadly correlated with the post-Dittonian sequence in the Brecon Beacons. The base of these beds is demarcated by the lower

of the two Abdon Limestones (compare with Wills, L. J., 1950). The Clee Series appears to be conformable upon the Dittonian strata below, and despite the absence of fossils, a correlation with the Senni Beds is suggested, though the upper part of the series may well be of Brownstones age.

2. The Upper Old Red Sandstone

(d) *Farlovian: Farlow Sandstones Series*

Typically and best-developed between Farlow and Prescott, the Farlow Sandstones also outcrop in the Benson's Brook section near the top of Titterstone Clee Hill, and at Cleeton. The Farlovian consists mainly of bright yellow, green and brown sandstones with bands of purple and green marl, and occasional pellet-beds. Some 400 ft. of beds are present, resting unconformably upon the Lower Old Red Sandstone.

Representatives of the characteristic Upper Old Red Sandstone fauna have been found at the base and at the top of the sequence. (See below and also Egerton, P. M. de G., 1862; Woodward, A. S., 1891; King, W. W., 1925, p. 387.)

H.W.B.

PALAEONTOLOGY

Elles and Slater (1906), Stamp (1923) and Straw (1929) have given extensive lists of the fossils from the Grey Downton Formation, whilst White (1935, 1938, 1946, 1948, 1950) has contributed much to our knowledge of the faunas of the Old Red Sandstone of the Welsh Borderland. Wills (1935) and Smith Woodward (1891) have also made important contributions, whilst Stensiö (1932) has described the cephalaspids from the area.

Within the Grey Downton Formation, the shelly fauna of the marine Ludlovian is replaced by a vertebrate and eurypterid assemblage. The Ludlow Bone Bed marks the first appearance of the vertebrate fauna in force, with *Thelodus* sp. scales in great abundance. Other forms present include *Cyathaspis banksi*, *Sclerodus pustuliferus* and acanthodian spines. Small inarticulate brachiopods sometimes occur with the mass of vertebrate material.

The Downton Castle Sandstones and the Temeside Beds may be extremely fossiliferous locally. The fossils are usually gathered into thin lenses of no great lateral extent, showing signs of water-sorting. The shelly fauna includes the zonal forms *Lingula minima* (Downton Castle Sandstones) and *L. cornea* (Temeside Beds), with *Holopella gregaria* and *Platyschisma helicites*, common at certain horizons, and a small number of lamellibranchs. Ostracods are often present in large numbers, while *Hughmilleria pygmaeus*, *Pterygotus anglicus* and *P. ludensis* are also frequently found. *Hemicyclaspis munchisoni* and *Sclerodus pustuliferus* represent the ostracoderms, but these and acanthodian spines are not common. Plants are represented at many

horizons, especially near the base of the group, by *Pachytheca*, *Cooksonia* and *Prototaxites* (*Nematothallus*) (Lang, W. H., 1937).

Two zones have been erected by White (1950) at the top of the Downtonian, that of the ostracoderm *Traquairaspis* [*Phialaspis*] *symondsi* above and of *T. pococki* below. A wide variety of other fossils occurs at these horizons, and the following have been found in the two zones: *Cephalaspids*, including *Didymaspis grindrodi*, *Tesseractaspis tessellata*, *Oniscolepis* sp., *Onchus* sp., *Plectrodus* sp., *Ischnacanthus* sp., *Poraspis* sp., *Onychodus* sp. and *Thelodus* sp. denticles. *Corvaspis kingi* has been found in the upper of these two zones, but has also been recorded from one locality in the zone of *Pteraspis crouchi* in the Dittonian.

The appearance of the pteraspids marks the beginning of the Dittonian, with the zone of *Pteraspis leathensis* at the base (White, E. I., 1950, p. 69). Above this is a zone characterised by *P. crouchi* but also yielding *P. rostrata*. Other forms present in this, the lower part of the Ditton Series, are cephalaspids, *Tesseractaspis tessellata*, *Poraspis* sp., *Weigeltaspis* sp., *Onychodus* sp., *Onchus* sp., *Ischnacanthus* sp., *Thelodus* sp., and arctolepid [acanthaspid] fragments. The only lamellibranchs, forms resembling *Modiolopsis complanata*, that have been found within the area are from the zone of *Pteraspis leathensis*.

Occasional bands of grey and green shale or siltstone contain abundant eurypterid and plant remains, often accompanied by large pellets of charcoal-like vegetable-matter. In the upper part of the sequence, here included within the Dittonian, occur further arctolepids and *Rhinopteraspis* cf. *leachi* White (1950, p. 56, for *R. dunensis* (Roemer) var. *leachi* White 1938, pp. 85-100).

The fauna yielded by the Farlow Sandstones consists principally of fragments of *Bothriolepis* sp., including *B. macrocephala* (Egerton, P. M. de G., 1862; Stensiö, E. A., 1948), *Holoptychins* sp., cf. *Eusthenopteron* and cf. *Sauripterus*.

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THE BROCKENHURST BEDS AT VICTORIA TILERY, BROCKENHURST, HAMPSHIRE

By A. G. Davis, F.G.S.

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SUMMARY.—Brockenhurst, Hampshire—the type locality for the marine facies of the Middle Headon Beds—had been unavailable to students for many years. In 1935, the Victoria Tilery presented an opportunity for a re-examination of the fauna. The present paper places on record the collections made by six observers.

The desilicification of flint pebbles in the Brockenhurst Beds is discussed.

1. INTRODUCTION

THE Brockenhurst Beds, the marine member of the Middle Headon Beds, have been well-described and studied in the past. The type-locality engaged the attention of Lyell when, in his youth, he lived at Cutwalk Hill, near Lyndhurst, and later, the railway cuttings and local brickyards were worked by F. E. Edwards, by H. Keeping and E. B. Tawney (1881, p. 109), by J. W. Judd (1880, p. 152, and 1882, p. 476) and others of this generation. Students have since been content to study the equivalent horizon at Whitecliff Bay in the Isle of Wight, for all the sections on the mainland had become overgrown or flooded. In 1935, Messrs. J. G. Turner and E. M. Venables collected some fossils which were recognised as Brockenhurst forms. They had recovered these from a spoil heap from a shallow hand-dug water-well sunk within the Victoria Tilery, near Brockenhurst, Hants.¹ This brick and tile yard is described by Shore (1890, p. 34) and White (1915, p. 46), but they do not record any fossil collections from it. The section is situated within Pignal Enclosure, half a mile eastward of the Balmer Lawn Hotel, but now it is abandoned and has become overgrown.

2. NEW MATERIAL

It seemed desirable to open up a new section and, to this end, Mr. Eyres, the manager, most kindly gave every facility. Two trial-pits were dug and collections made with the co-operation of Messrs.

¹ Note—A warning! About 1937 a considerable amount of fossiliferous Middle Barton Clay from a well-digging near Fordingbridge was dumped in the Tilery.

J. G. Turner, E. St. J. Burton and D. Curry. The working-face varies from 12 to 20 ft. in depth and consists of weathered, brown or yellowish, clayey loams. Flooding occurs as soon as these depths are reached when the working is abandoned and a new pit is dug; Pignal Enclosure is, in fact, riddled with old workings. The weathered material produced the best coloured products, so there was little incentive to deepen the workings. Mr. Eyres very kindly made a trial-hole below the 1936 workings (flooded by 1938), and from this, the following section could be made out:

Humus and soil	...	...	...	6 in.	} (Brockenhurst Bed)
Brown and yellow loam	...	...	...	12 ft.	
Brown loam with moulds of shells	...	...	...	2 ft.	
Decayed <i>Ostrea ventralabrum</i> layer	...	...	...	6 in.	
Layer with ironstone nodules	...	...	...	5 in.	

The specimens obtained on the spoil-heap from the shallow well, were unweathered and beautifully preserved and were of a cream or grey colour. In this condition they were the envy of earlier workers who only had limited success. They occur in lenses, which have escaped oxidisation, and it was hoped in vain that a lens of this nature might be met with in the trial-holes. It was impossible to sink near the well itself as this was situated under crops in a garden.

A trial-hole was made in the overgrown workings at the eastern limit of the yard where a hole about 4 to 5 ft. in depth was expected to reach the Brockenhurst Beds. A square of turf was cut for the purpose, and it was noticed that the turving-iron sliced clean through the flint pebbles. These were found to be desilicified, a condition often met with in the Brockenhurst Beds. They occurred more commonly here than in any other part of the works. The 'sectioned' chalky-white pebbles contrasted strongly with the ochreous clay in which they were embedded. This trial-hole showed the following:

Yellowish, weathered clay with pebbles at top, irregularly scattered below	...	...	...	4 ft.
Yellow-brown, loamy clay with moulds of shells and nests of race (Brockenhurst Bed)	...	...	...	2 ft.
Layer of nodular ironstone concretions, many with concentric rinds, in greenish, clayey loam	...	...	...	5 in.
Stiff, greenish-yellow clay	...	...	...	2 ft. 6 in.

After failing to find well-preserved fossils in this trial-hole, another was opened in overgrown workings on the opposite side of the enclosure, near the entrance to the Tilery. Here weathered fossils were quite plentiful, the best-preserved specimens occurring towards the base of the bed where it was in contact with the greenish clay below. The section is as follows:

Brown loams	...	...	...	3 ft.
Shelly, brown loam (Brockenhurst Bed)	...	...	...	2 ft.
Layer with ironstone concretions	...	...	...	4 in.
Greenish clay with <i>Limnaea</i> and <i>Potamomya</i> (Lower Headon Beds)	...	...	seen for	1 ft. 6 in.

3. THE DESILICIFIED FLINT PEBBLES

The decomposed pebbles, found in the Tilery, differ from the better-known found in the Brockenhurst Beds at Whitecliff Bay, in being less plastic. At the latter locality, they may be squeezed and moulded between the finger and thumb. At the Tilery, they are less decomposed and, in appearance, more like the affected pebbles of Knockmill, Kent.

At Whitecliff, the pebbles often retain their individual colours but, at the Tilery, they are bleached white. The problem of the desilicification of the flint has not been finally settled. At Whitecliff, where the process of decomposition has practically reached finality, the pebbles are in unweathered beds and in juxtaposition with molluscan shells which have remained unaffected and retain some of their original colouring.

The decomposing agent does not attack the micro-fossils included in the original flint, and these have obviously been replaced by a form of silica which has resisted the dissolving agent. If the Whitecliff plastic pebbles are dried and then placed in water, a soft white mud is produced. By sifting, micro-organisms are readily recovered, and these include Cretaceous Foraminifera, Polyzoa, Ostracoda and sponge débris in quantity, beautifully preserved and translucent.

4. FAUNAL LIST

This list has been compiled from the collections made by Messrs. E. St. J. Burton, D. Curry, J. G. Turner, E. M. Venables, A. Wrigley and the author. The collections made by Messrs. Turner and Venables are deposited in the British Museum (Natural History).

FOSSILS COLLECTED FROM BROCKENHURST BEDS VICTORIA TILERY

HYDROZOA : *Graphularia wetherelli* M. Edwards & Haime. 2.¹

ANTHOZOA : *Solenastraea beyrichi* Duncan. 1. The rarity of corals is remarkable, for at the nearby Whitley Ridge locality, large numbers are recorded.

POLYZOA : *Conopeum* sp. 3.
Onychocella magnoaperta Gregory. 2.
Umbonula bartonensis Gregory. 6.
Teichopora clavata Gregory. 8.
Trypostega sp. indet. 2.

CRUSTACEA : *Balanus unguiformis* J. Sowerby. 2.

MOLLUSCA : *Anomia* sp. indet. 1.
Ostrea ventilabrum Goldfuss. Abundant.
Chlamys bellicostata (S. Wood). 6.
Pteria sp. indet. 4.
Modiola nystii Nyst. 13.
Modiolus sp. indet. Fragments of a coarsely-rayed species.

¹ Numerals indicate frequency of occurrence. Common, indicates that twenty specimens were obtained in a few hours of work. In compiling the above list, the author has received the valuable assistance of Messrs. D. Curry and A. Wrigley. Dr. L. R. Cox and Mr. C. P. Castell gave facilities for examining the J. G. Turner Colln. in the British Museum (Natural History). To these, the author is greatly indebted.

- MOLLUSCA:** *Nucula headonensis* J. Morris. 2.
Unio sp. indet. Umbonal fragment only.
Venericardia deltoidea (J. Sowerby). Common.
Veniella pectinifera (J. de C. Sowerby). 2.
Nemocardium hantoniensis (Von Koenen). 4.
Cardium (*Orthocardium*) *porulosum* Solander. 2.
Cyrena sp. indet. 2 fragments.
Cyprina sp. indet. 2 hinge fragments.
Diplodonta sp. indet. 1.
Pitar sp. indet. A small form, common.
Cordiopsis incrassata (J. Sowerby). Common.
Gari compressa (J. de C. Sowerby). 2.
Psammobia aestuarina Edwards MS. 1.
Panopaea sp. indet. Fragment only.
Corbula cuspidata J. Sowerby. Common.
Corbula pisum J. Sowerby var. *fortisulcata* (Edwards MS.). Common.
Corbula descendens Von Koenen. 2. Also occurs at Whitecliff Bay, Isle of Wight. Not previously recorded from England.
Lentidium edwardsi (Tawney). 7.
 ? *Pholas* sp. indet. Crypts, some very large, in ferruginous concretions at the base of the bed.
Teredo sp. indet. One fragment of a tube.
Hippochrenes oligocenicus (Lefèvre). Fragments only.
Aporrhais speciosa (Schlotheim). 4.
Rimella rimosa (Solander). Common.
Ancilla subulata J. Sowerby (*non* Lamarck). 14.
Sconsia ambigua (Solander). 1. A single row of prominent knobs is present on the shoulder.
Turricula transversaria (Lamarck). Common.
Asthenotoma aff. *helicoides* (F. E. Edwards) [? = *bi-lingulata* von Koenen]. 2.
Gemmula odontella (F. E. Edwards). 1.
Genota pyrgota var. α (F. E. Edwards). 4.
Turricula cymaea (F. E. Edwards). 5.
Bathytoma hantoniensis (F. E. Edwards). Common.
Hemipleurotoma plebia (J. Sowerby). 1.
Turris headonensis (J. Morris). 7.
Conorbis procerus (Beyrich) [? = *seminudus* F. E. Edwards] 5.
Voluto spina spinosa (Lamarck). Common.
Voluto spina dunkeri (Speyer). Common.
Borsonia sulcata (F. E. Edwards MS.) = Forbes. 12.
Raphitoma sp. indet. Unlike the Upper Eocene species and occurs at Whitecliff Bay, Isle of Wight. 2.
Lyria decora (Beyrich). 12.
Conomitra cf. *fusellina* (Lamarck). 8.
Gibberula vittata (F. E. Edwards). 7.
Melongena minax (Solander). 1.
Murex hantoniensis Wrigley 12.
Typhis pungens (Solander). 12.
Clavilithes conjunctoides Grabau. Common.
Pollia (*Tritonidea*) *labiata* (J. de C. Sowerby). Abundant.
Strepsidura armata J. de C. Sowerby. 8.
Bonellitia cf. *evulsa* (Solander). 1.
Bonellitia pyrgota (F. E. Edwards). 12.
Unitas (*Uxia*) *elongata* (Nyst). 4.

- MOLLUSCA : *Odostomia* sp. Several.
Scala laevis J. Morris. 2.
Tarebia acuta (J. Sowerby). 1.
Hemicerithium cf. *gardneri* Cossmann. 2.
Xenophora petrophora Von Koenen. 1.
Viviparus lentus Solander. 1.
Polinices hantoniensis (Pilkington). 4.
Euspira headonensis Wrigley. Several.
Natica epiglottina Lamarck. 1.
Natica burtoni Wrigley. 9.
Globularia grossa (Deshayes) form. *harrisi* Cossman. 3.
Calyptraea striatella Nyst. Common.
Capulus squamaeformis (Lamarck). 1.
Roxania attenuata (J. de C. Sowerby). 2.
Roxania extensa (J. de C. Sowerby). 1.
Bullinella cf. *denudata* (Deshayes). 1.
Tornatellaea sp. indet. 1.
- PISCES : *Odontaspis* sp. indet. 3.
Eugaleus sp. indet. 1.
Myliobatis sp. indet. 1.
Lepidosteus sp. indet. 1.
Otolithus spp. indet. 4.
- REPTILIA : *Diplocynodon* sp. indet. 1 tooth.
Trionyx sp. indet. Fragment of carapace.
- MAMMALIA : An *Ancodon*-like incisor (J. G. Turner Colln.).

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SACCAMMINOPSIS FROM THE SILURIAN

By Robert H. Cummings, Ph.D., B.Sc., F.G.S.

[Received 28 June 1951]

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SUMMARY.—The specimens, from the Woolhope and Wenlock horizons of Shropshire and adjacent counties, defined by Brady and others as *Lagena*, are re-described and identified with *Saccamminopsis fusulinaformis* (M'Coy), already known to exist in the Ordovician rocks of the Girvan Area.

1. INTRODUCTION

IN an appendix to the paper by Smith (1881, p. 75) on the micro-fauna of the Silurian of Shropshire, T. Rupert Jones provisionally listed three varieties of *Lagena vulgaris* Williamson from five localities, the three varieties being var. *laevis* Montagu (with tubuliferous neck), var. *clavata* d'Orbigny and var. *sulcata* Walker and Jacob.

These specimens, together with new forms collected by H. B. Holl from the Wych, Malvern, were described by Brady (1888, p. 481) who identified all the forms as belonging to the genus *Lagena* Walker and Jacob 1798. Selecting four groups from the collection, he ascribed each of these to a modern species. In this way the geological ranges of *Lagena globosa* Montagu, *Lagena clavata* d'Orbigny, *Lagena laevis* Montagu and *Lagena sulcata* Walker and Jacob were extended back into the Silurian.

Recently, through the kindness of Mr. C. D. Ovey, I had the opportunity of examining this Silurian material at the British Museum (Natural History).¹ The following revision provides another instance of a record of hyaline-calcareous Foraminifera in the Palaeozoic proving erroneous. In this respect the results may be regarded as a continuation of work already done in Britain by Professor Alan Wood (1947 and 1949).

2. GENERAL DESCRIPTION OF THE FORMS

It is a significant feature of Brady's paper that a general description of the whole group is given and not a specialised one for each of the

¹ British Museum (Natural History) registration numbers quoted in this paper are preceded by the letters P. or ZF.

four separate species he identified as being present. He regarded the group as members of the genus *Lagena* and, from amongst them, selected specimens as similar to given species on the basis of a single morphological character. Thus forms with a tapering neck are *Lagena laevis*; those with a 'pointed base' become *Lagena clavata*; those possessing superficial costae are included in *Lagena sulcata*.

When the complete collection is reviewed, it can be demonstrated that there are no discontinuities in the range of variation within the group, and no special morphological character which is confined to only some of the specimens of the group. It may well be, therefore, that one species is present and that this is subject to considerable variation in size and contour.

The tests are flask-shaped, fusiform, or globular with the apertural end varying from a long, tapering, somewhat conical extension to a short, angular, and relatively broad neck. The broadly rounded to sub-conical aboral end may possess either a short protuberance in the smaller forms or a small, low depression of the surface in the larger specimens. Probably due in part to crushing, the cross-section ranges from circular to ellipsoidal.

There are no sutures or septal constrictions on the exterior, but a ridge of material forms a collar round the elongate neck-like extensions of some specimens. This collar is highly variable in shape, size and relative position.

The surface is generally rough and somewhat granular due partly to weathering, partly to recrystallisation, and partly to encrustation (e.g. *L. laevis* Brady, 1888, fig. 10; P.41027). The test-wall is calcareous and homogeneous, being composed of irregular calcitic grains bound by calcareous cement, except in those cases where silicification has taken place. It is moderately thick, usually one-thirtieth the total length of the test, and the uneven character of both the interior and exterior surfaces is probably due to alteration. Faint traces of a fibrous structure have been noted and these may indicate an original hyaline texture. Frequently the walls are completely destroyed and the specimen is a mere mould in calcite, or rarely silica, of the interior of the test (e.g. *L. laevis* Brady, 1888, fig. 6; P.39334).

At the termination of the longer, conical, elongated end, there is often a small, simple, circular aperture which may be closed by infiltrated material. There is also, especially in the large specimens a small, shallow, conical depression often present at the apex of the opposite end (e.g. *L. globosa* Brady, 1888, fig. 2; P.39333). This feature, overlooked by Brady, is regarded as another aperture which may in some specimens be closed by infiltrated material. Furthermore, in those cases where this depression is replaced by a narrow conical protuberance, this may represent the cast of a second minor apertural neck (e.g. *L. laevis* Brady, 1888, figs. 7-9; P.39335).

The dimensions vary greatly and hence average values are meaningless. The size-ranges of Brady's figured specimens are:

Total length	...	...	1.41 mm.–2.50 mm.
Maximum diameter	...	...	0.81 mm.–2.01 mm.

Forms of smaller dimensions than these occur but they are mere silicified internal moulds.

It will be seen that these figures are much larger than the minimum values given by Brady who cited 0.28 mm. as the minimum value of the total length. When all the specimens are reviewed, the marked difference in size, which Brady considered to occur between the forms in the collection of T. R. Jones and those collected by J. Smith, does not appear to exist. A comparison of the dimensions, now given in the table below, with Brady's figures (1888, pl. 13) shows that his magnification values must be incorrect. This is probably the cause of the inaccurate statement in the text.

3. RELATIONSHIP TO THE GENUS *LAGENA*

From the general description given above, it appears that there are certain morphological features which exclude these forms from the genus *Lagena* and from the Upper Palaeozoic genus *Archaelagena* Howchin.

Though the relatively large size of the specimens cannot, in itself, be regarded as sufficient evidence for exclusion, it must be taken into consideration with the other features. These Palaeozoic forms have a volume some five to twenty times that of normal, modern, species of *Lagena* where only in very exceptional cases does the total length or maximum diameter of the test exceed 1 mm. (see table).

TABLE SHOWING RELATIVE DIMENSIONS (in mm.) OF THE
VARIOUS SPECIMENS EXAMINED

	Length		Diameter	
	mean	range	mean	range
' <i>Lagena globosa</i> ', Silurian (based on 3 specimens, Brit. Mus.) (P.39333)	2.4	2.1–2.5	1.81	1.44–2.0
' <i>Lagena clavata</i> ', Silurian (one specimen). (P.39333)	1.99	—	0.97	—
' <i>Lagena laevis</i> ', Silurian (based on 15 specimens). (P.39335)	1.74	0.8–2.1	0.96	0.60–1.2
<i>Sac. fusulinaformis</i> , Ordovician (based on 8 specimens)	1.60	1.3–1.7	0.84	0.68–1.0
<i>Sac. fusulinaformis</i> , Carboniferous (based on 30 specimens)	2.5	1.0–3.9	1.97	0.70–2.9
<i>Lagena globosa</i> , Recent	0.23	—	0.26	—
<i>Lagena clavata</i> , Recent	1.09	—	0.21	—
<i>Lagena laevis</i> , Recent (based on 3 specimens)	0.47	0.3–0.6	0.22	0.17–0.3

Although members of the modern Lagenidae—and especially of the genus *Lagena* itself—show a wide variation in form, there is a

very high degree of symmetry within any one specimen. This is not the case in the Palaeozoic specimens, for even the position and shape of the neck-collar, characters which cannot be altered by crushing, are always irregular.

The wall of the test in *Lagena* is relatively thin and hyaline-calcareous in composition. In these Silurian specimens the wall is moderately thick and made up of an irregular mosaic of calcite-grains bound by calcareous cement, as in the case of the Carboniferous specimens examined by Sollas (1921, pp. 193–212). It is true that they may have had an original hyaline structure which has been recrystallised, for alteration has undoubtedly taken place and traces of a fibrous structure occur rarely, but there remains the difference in thickness.

The presence of an aperture at both ends of a *Lagena*-test is a very rare feature if, indeed, ever present at all; any such specimen should in any case be referred, according to definition, to another genus. An example of a '*Lagena*' with a double aperture is the specimen of *Lagena clavata* Williamson figured by Cushman and McCulloch (see table and Fig. A). In this, and in all forms so characterised, as far as can be ascertained by the present writer, the test is long, slender, fusiform and tapering regularly and evenly in both directions—a description which can hardly be applied to any of the Palaeozoic forms and certainly not to those identified by Brady as *Lagena clavata*.

In addition to recording the morphological differences that exist between these forms and the genus *Lagena*, the results of identifying these Silurian forms as lagenids should be recognised. *Lagena* is probably polyphyletic and is regarded by most modern workers as an end-form or as a collection of such forms. If we are to look upon Brady's records as correct, we imply the presence of a host of calcareous forms in the Palaeozoic, of which none are known at the present time in spite of a great deal of research by Moreman (1933), Dunn (1942) and others. Furthermore this would stand as the only record of the genus prior to the Trias. The Carboniferous species of *Lagena* have been examined by the author and are found to have been incorrectly identified and, indeed, belonging, in at least two instances, outside the Foraminifera.

4. THE PRESENCE OF *SACCAMMINOPSIS* CF. *FUSULINIFORMIS* (M'COY) IN THE LOWER PALAEOZOIC

Specimens of *Saccamminopsis fusulinaformis* (*Saccammina carteri* of Brady and others) have been recorded by various authors from the Ordovician of the Girvan Area of Scotland. Lapworth (1882, p. 537) records the species as occurring in the Calcareous Group of the Stinchar Valley, above the limestone in the Tramitchell Quarries of the Assel Valley, and from the Millenderdale Area. From Tramitchell

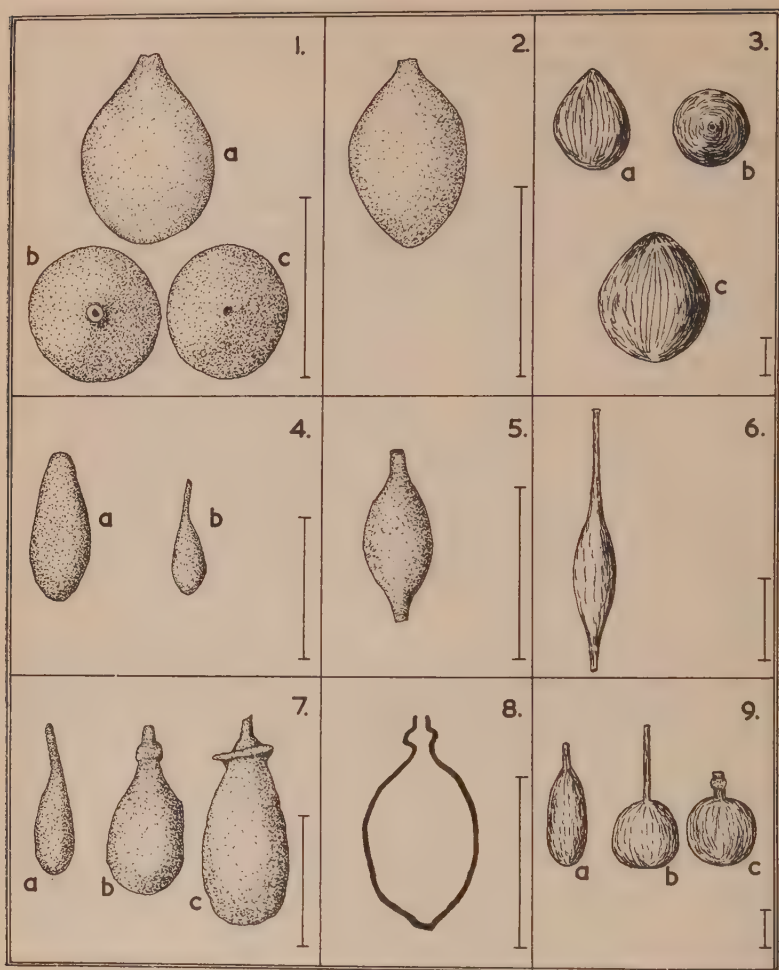


FIGURE A

1. '*Lagena globosa*', as figured by Brady, 1888, pl. 13, fig. 1. (a) Lateral view, (b) Apertural view, (c) Basal view showing shallow depression. $\times 20$. (P.39333(i).)
2. *Saccamminopsis fusulinaformis* (M'Coy), Carboniferous. Lateral view only. $\times 20$. (P.28372.)
3. *Lagena globosa* Montagu—Recent; as present in the *Challenger* Collection. (a and c) Lateral views of two different specimens; (b) Apertural view of specimen shown in (a). All $\times 70$. (ZF.1665.)
4. '*Lagena clavata*'—as figured by Brady, 1888, pl. 13, figs. 4 and 5; (a. and b) Lateral views of different specimens. Both $\times 20$. (P.39333(ii).)

they are listed as *Saccamina carteri*, and hence it is assumed that Lapworth regarded these Ordovician forms as identical, or nearly so, with typical Carboniferous specimens.

After recent examination of examples of this form collected by Dr. A. Williams from Tramitchell, and of thin-sections of foraminiferal limestone from the same area, including some in the British Museum (Natural History), I have little doubt that they are to be compared with Carboniferous forms of *Saccamminopsis* and may be listed as *Saccamminopsis* cf. *fusulinaformis* (M'Coy). This would confirm Lapworth's original record.

5. LAGENA AND SACCAMMINOPSIS IN THE PALAEOZOIC

When the specimens of the supposed lagenids from the Silurian of Shropshire are compared with either Ordovician or Carboniferous examples of *Saccamminopsis*, it is obvious that the two are identical. All the morphological features listed by Brady, and those described above, can be found in specimens from both the Ordovician and Carboniferous.

The wide variation in shape noted amongst the Palaeozoic '*Lagenae*' is also present in *Saccamminopsis*. The close relationship in size between the two groups is shown in the table (p. 222) as well as the marked difference that exists between these specimens and modern representatives of the Lagenidae. The double-aperture and fusiform features of the '*Lagenae*' are matched in the *Saccamminopsis*-group by the openings in the ends of the stoloniferous tubes or by the position of attachment of these tubes. The presence of neck-collars of similar characters to those noted above can be found in Carboniferous forms of *Saccamminopsis* in which this feature is also highly variable in shape, size and position. The surface, wall-structure and thickness, and mode of preservation are identical in both cases.

In addition it should be noted that the identification of these '*Lagenae*' as *Saccamminopsis* does not raise any important problems of phylogeny and is more in keeping with other proven information.

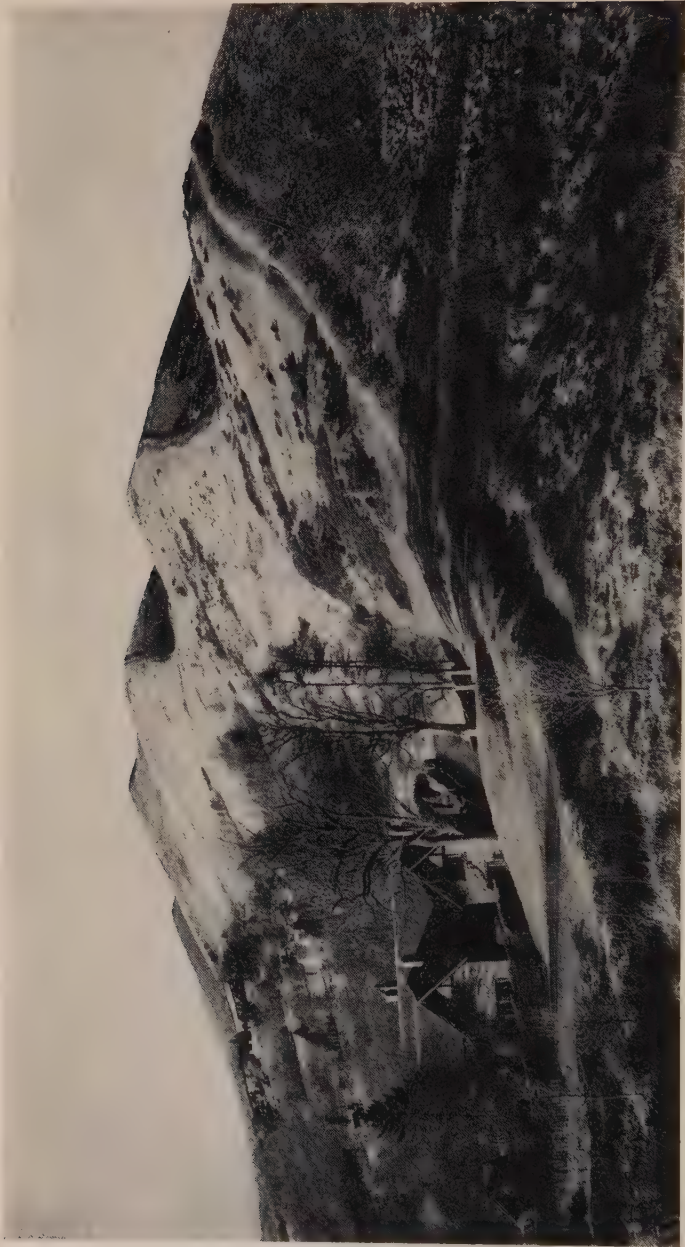
5. *Saccamminopsis fusulinaformis* (M'Coy), Carboniferous. Lateral view only. $\times 20$. (P.28372.)
6. *Lagena clavata* (d'Orbigny), Recent; as figured by Cushman & McCulloch, 1950, pl. 44, fig. 13a and p. 332. Lateral view only. $\times 60$.
7. '*Lagena laevis*', as figured by Brady, 1888, pl. 13, figs. 6, 7 and 9. Lateral views of different specimens. $\times 25$. (P.39334-5.)
8. *Saccamminopsis fusulinaformis* (M'Coy), Carboniferous. $\times 25$. Diagrammatic section of specimen showing 'neck-collar' feature noted by Brady in the Silurian specimens. $\times 25$. (P.28372.)
9. *Lagena laevis* Montagu, Recent; as present in the *Challenger* Collection. Lateral view of different specimens. All $\times 70$. (ZF.1696.)

The relative size of the various figured specimens is shown by the lines of maximum length.

The author would like to thank Professor T. Neville George, Professor Alan Wood and Mr. C. D. Ovey for guidance and assistance during the course of this work.

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THE MALVERN HILLS, NORTH OF LITTLE MALVERN, BUT LOOKING NORTH FROM THE WEST SIDE

STRUCTURE AND ORIGIN OF THE MALVERN HILLS

By Frank Raw, D.Sc., F.G.S., F.Z.S.

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ABSTRACT AND INTRODUCTION.—Half a century ago T. T. Groom in 1899 and 1900 published his two papers on this subject. Groom built on his predecessors, as must the writer: the most important sources were J. Phillips, Holl and Callaway, but there were many others. Groom's views seemed to gain immediate acceptance; and have not been seriously opposed except by Falcon (1947), who doubts the existence of an eastern boundary fault and would put the main uplift before Upper Coal Measures time. Groom repeated his theory in *Geology in the Field* (1910). For many years the writer, while deeply indebted to Groom for his facts, has held a view very different from Groom's as to the essential structure and the origin of these hills. Groom stressed the rôle of compressive and elevative stresses of Armorican date; and he limited tensile stresses, believed to be Tertiary (1910, p. 736) to the eastern fault. The writer, accepting Armorican and Tertiary movements as the main agents, claims that the Armorican were more varied and much more extensive than Groom envisaged.

According to Phillips (1855), 'the Malvern Hills form one of the most beautiful and singular ranges of mountains in the world': they are indeed remarkable in several ways. Topographically they are peculiar, both because they stand up so magnificently above the low plain of the Severn and because they are so serrate in outline in contrast with the levels of the upland plains; and geologically they are noteworthy, not only for these reasons, but also because they consist of such coarsely crystalline Archaean rocks in so extremely narrow an area, in direct contact on one side with Mesozoic, on the other with Palaeozoic sediments; and, in the writer's view, because they owe their structure and emplacement to movements of four different periods, and of two quite different kinds—tangential compression and tension; and lastly because they owe their survival as hills to having been dropped down as well as pushed up.

1. HISTORY OF PREVIOUS INVESTIGATION

THE history of previous research was briefly dealt with by Groom, most of the papers having followed the memoir by Phillips (1848). But so peculiar and accessible a mountain range early claimed the attention of geologists; and even the earliest paper is of special interest for comparison with later views.

The Geological Society was founded in 1807; and already in 1810 Leonard Horner, the second Secretary and later a President, gave a paper 'On the mineralogy of the Malvern Hills' with a section on one

of the plates (1811). He contrasts the 'granitic' rocks of the range with the sedimentaries on either side, but these also with one another, both in nature and disposition, the flat-lying 'red sandstone' to the east contrasting with the steep strata to the west, which, indeed, he showed to be inverted at the contact with the rocks of the range. This he attributed to 'some violent force that has elevated them from the horizontal position'. But he claims the range as intrusive granite, explaining its intimate relations with the sedimentary rocks as due to its intrusive veins. Further it appeared to him 'likely that the red sandstone existed previous to the elevation of the range', and that it covers stratified rocks similar to those of the west, from which area it had been 'gradually washed away'.

2. DEVELOPMENT OF THE AUTHOR'S THEORY: CRITICISM OF PREVIOUS CONCEPTIONS

The Malvern Hills display a long, narrow, parallel-sided strip of country, occupied by resistant Pre-Cambrian rocks between older Palaeozoics to the west and relatively flat Keuper Marl to the east (Fig. 1). In contrast with the low dips of the latter, the Silurian to the west, where it borders the Pre-Cambrian, is not only strongly folded, but everywhere somewhat inverted except to the south in the region of Midsummer Hill and Raggedstone Hill, where, however, it is very steep: again, south of this, the Cambrian is inverted, adjoining Chase End Hill.

The Pre-Cambrian rocks are predominantly the coarsely crystalline, plutonic igneous and metamorphic or foliated Archaean or 'Malvernian' (Callaway, C., 1893; Groom, T. T., 1900, p. 140 *et seq.*), which extend a distance of $7\frac{3}{4}$ miles from north to south, with a maximum width of $\frac{2}{3}$ mile in North Hill—a ratio of 12 to 1. It is probable that this extreme narrowness of the area is responsible for the serrate character of the range, which is highest where it is widest, and lowest where narrowest. East of the somewhat outlying Hereford Beacon the place of the Malvernian along the axis of the range is taken, for a mile, by the 'Warren House Series' of Pre-Cambrian volcanics, regarded by Callaway (1880) as equivalent to the Uriconian, whereas the Malvernian was compared with the Primrose Hill rocks, also of Shropshire. The boundaries of the Malvernian, east and west, as well as of the Warren House Series, are now, perhaps universally, regarded as faults. Besides being exposed at the surface, the bounding faults have twice been recognised and studied in the Malvern Tunnel, first by Symonds and Lambert (1861, p. 152), second by T. Robertson (1926, pp. 162–73) (see Fig. 2). These tunnel-sections are of great importance for the interpretation of the structure. Study of the second section confirmed the conclusions obtainable from the first. The faults bounding the Malvernian are sub-parallel at the surface, and have been claimed to have the same

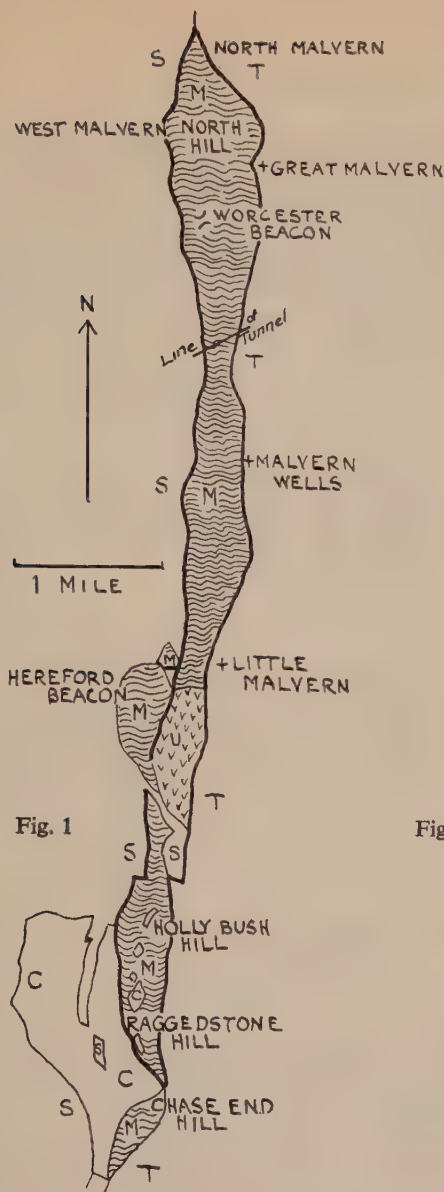


Fig. 1



Fig. 2

FIG. 1.—Geological Sketch-Map of the Malvern Hills redrawn, after T. T. Groom (*in* Pocock, R. W. and T. H. Whitehead, 1935, p. 13). The faults, bounding the axis, are here strengthened to distinguish it from the detached Malvernian areas of Hereford Beacon and Chase End Hill.

M=Malvernian, U=Uriconian, C=Cambrian and Ordovician, S=Silurian and T=Trias (Keuper).

FIG. 2.—Section along the line of the Malvern Tunnel, redrawn after T. Robertson (1926). The fault bounding the Archaean on the west is vertical in the tunnel; and the crest above the tunnel is less than represented, about 980 ft. O.D. instead of 1050 ft. as shown. Length of section=1 mile.

direction of hade. Nevertheless, they were claimed by Groom as being of quite different ages and of quite different natures! Groom regarded the eastern as a normal fault of small throw (1898, p. 873; 1900, p. 195) and of Tertiary age (1910, p. 736); whereas the western he regarded as an 'upthrust' of the Malvernian (1900, pp. 182, 194), of Coal Measures (Armorican) date, which had overturned the Silurian (Fig. 3). The writer suggests that they are faults of the same series; and that both are normal or tension faults, together constituting a pair of step-faults (Fig. 4).

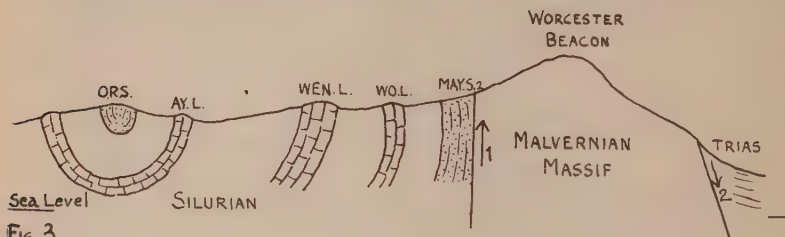


FIG. 3

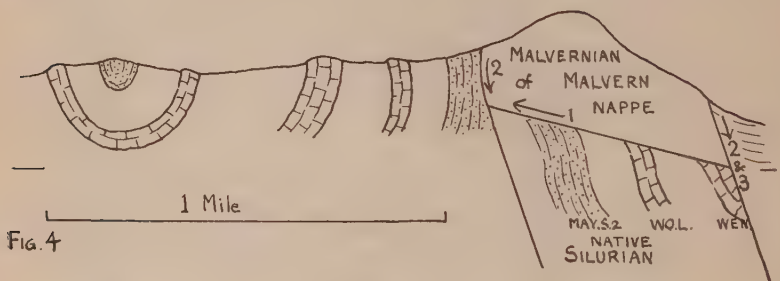


FIG. 4

FIG. 3.—Sketch-section W-E. through Worcester Beacon on the theory of T. T. Groom.

FIG. 4.—Same section on the present writer's theory.

But the Pre-Cambrian areas of the Malvern Hills are naturally divisible into: the *axis* extending from North Hill to Raggedstone Hill; and the *detached areas* of Hereford Beacon to the west and Chase End Hill to the south.

The faults bounding the axis on the west, where their hade is indicated by exposures, have especially high inclinations. Such an approach to the vertical is not at all in harmony with tangential compressive stress but suggests emplacement under tangential tension. All of Groom's sections of the west boundary suggest the latter (e.g., 1899, figs. 3 to 17—fig. 16 is an exception, but this is across the Chase End mass; so also, 1900, all the sections except figs. 2 and 3 across Hereford Beacon—see Fig. 5). In addition Groom's frequent references to the good preservation of identifiable Cambrian

or Silurian fossils in rock close to the junction, is much more consonant with emplacement under tension than compression.

The 'detached areas' on the contrary have very different western boundaries. Hereford Beacon lies west of the axis; and it is, perhaps, significant that the axis east of it is there made of the Warren House Series, and that immediately south of this there is actually Silurian forming the axis. The second detached area, Chase End Hill, is separated from the Malvernian of Raggedstone Hill by the eastern angle of the only large Cambrian area where the eastern and western faults come together, as they do also north of North Hill. It is significant that both these detached areas are separated from the axis by faults; and that the bounding faults on their west are of low hade, and, on the map, arch out westward. These last are claimed by Groom as low-angled thrusts, along which the Malvernian has been pushed westward over the underlying Palaeozoics, respectively Silurian and Cambrian, overturning them in the process; and the present writer accepts them as such. Groom, however, associated them with the steep-hading faults bounding the axis on the west, and regarded both as upthrusts due to Armorican compressive stresses.

In contrast with the two detached areas, where the faults are thrusts of low hade, the quarry exposures of the western boundary-faults, both in the southern and northern sections of the chain, are practically vertical and substantially parallel to the bedding in the adjoining Silurian and Cambrian. Groom in his papers frequently comments on this. It should be noted, too, that, though Groom estimated the 'dip' of the western fault in the tunnel as 65 degrees (1899, p. 150), Symonds and Lambert (1861, p. 157), who carefully studied this contact in the tunnel, state: 'The syenite passed, we find limestone and shales of the Upper Llandovery epoch full of fossils resting perpendicularly against the wall of syenite, fig. 5—and in that figure the junction is represented as vertical.' Robertson, who studied the fault in the second tunnel parallel to the first and 44 ft. away, also states that the western fault is there vertical, and he estimated the general 'dip' of the fault from the surface as 75 or 80 degrees (1926, p. 167). The estimated dips given by these observers are probably secondary, resulting from denudation. This fits in, therefore, with the other exposures indicating approximate verticality. Groom does not appear to have ever entertained the idea of the normal nature or eastern throw of the western fault. To him it was always an upthrust of the Archaean, because he had no idea of the Archaean coming down from above. It may be noted that only a very small fraction of the high angle can be attributed to the uptilt to the west of the country as a whole.

But accepting, as we must, the thrust-planes under Hereford Beacon and Chase End Hill, and the folding and over-folding of the Palaeozoics as typical effects of compressive stresses, it is clear that the steep faults, bounding the western side of the Malvern axis, are

entirely out of harmony with them and strongly suggest tensile stress. Further, the parallel outcrop of the western and the eastern faults is a strong argument against regarding one as Palaeozoic and the other as Tertiary; whereas, if both are contemporary products of the same stress, their parallelism of outcrop is normal. Further, that the stress determining the fault on the east was tensile, there can be no doubt. It is suggested by its steepness and by the obvious downthrow of the Trias to and under the Severn plain (see also below). Falcon (1947, pp. 229, 235-40) claimed that the eastern boundary is not a fault, but merely an unconformable junction of the Trias against the Malvernian. This, however, is easily proved to be an error both by the actual exposure of the fault and by the nature of the Keuper Marl in the Belmont Brick Works of Newtown, North Malvern; for North Hill towers about 1000 ft. above, but the marl contains no Malvernian fragments. The same conclusion follows from consideration of the Malvern Wells railway cutting and the eastern fault in the tunnel. The facts prove a post-Triassic throw of this fault.

If Groom's view were correct, we might expect that the rocks meeting in the western fault, having suffered from Armorican movements under great compressive stress, would be greatly sheared, in contrast with those meeting at the eastern fault, which, brought together under Tertiary tensile stress, might be expected to be much less affected.

On the contrary, in the first tunnel-sections, according to Symonds, there was at the western fault little brecciation; and the 'syenite' without any 'symptom of metamorphism' was followed immediately by fossiliferous Llandovery, from which was secured a specimen of *Pentamerus laevis*; whereas, at the eastern boundary, the Keuper Marl was succeeded by 20 ft. of breccia with a marly base. The second tunnel-section, again, closely agreed with the first. The facts seem to be in full support of the theory that the eastern fault is one of much greater throw, and throw of two different periods.

Further, had the Malvernian of the Hills been in truth the top of the crystalline crust of the earth, as on Groom's theory, and bounded on the west by a very steep fault, we might expect that this would be highly mineralised. The facts are quite otherwise, and the extraordinary purity of the springs (e.g., Schwepes) emerging around the Malvernian, suggest that it is all highly superficial water, which, being unable to dissolve much from the ancient rock, remains remarkably pure, though the entire absence of cultivation and the absence of woodland are doubtless important contributory factors (Bennett, A., 1942).

But if both the east and west faults are of the same series and the same type—both normal faults drooping east—this implies that the continuation of the Malvernian of the hills, besides lying deep beneath the Severn plain, existed also at one time above the country to the west. An example of such a condition still existing, is

the detached area of Hereford Beacon. Here Malvernian still rests upon thoroughly overturned Silurian; and overrides westward in succession—May Hill Sandstone, Woolhope Limestone and Wenlock Shale. One can attribute the inversion to the same stress which caused the westward transport of the Malvernian over them. Further, the area of inversion in front of this mass suggests a former extension of the mass in this direction; but how far, we cannot say, because the land now falls in that direction instead of rising, as formerly obtained for both the thrust plane and its Palaeozoic floor. In Chase End Hill also, though the Cambrian beds strike at 45 degrees to the Malvern Hills axis, the rocks are overturned in front of and presumably beneath the existing Malvernian, which again had a previous greater extension to the west.

This theory as to the nature of the faults bounding the Hills carries a further necessary implication, namely, that the Malvern axis throughout rests upon a thrust-plane which presumably descends eastward, and is underlain by much folded and overturned Cambrian and Silurian; and that the same thrust-plane exists under the Severn plain.

This is far removed from Groom's ideas. Of the Malvern Hills in his 'Summary' he writes (1900, p. 193): 'The western margin of the Archaean massif appears everywhere to be defined by a fault, in some cases about vertical, in others reversed, sometimes with a considerable hade.' Note that he calls the Archaean a 'massif' and that the western boundary-fault of the axis (e.g., in the tunnel) is 'reversed'. He regarded the thrust-planes bounding the Malvernian of Hereford Beacon and of Chase End Hills as mere variants of the steep faults bounding the west margin of the Malvern Hills axis. In his view the whole is a unit, an Archaean massif *in situ*, which in Armorican time was defined on the west by great uplift relative to the ground beyond, and later, in Tertiary time, was defined on the east by the eastern boundary-fault through being left behind when the region beyond sank. Thus he makes the axis part of a massif, a part bounded by faults of different ages and quite different natures; a massif the rest of which is beneath the Severn plain (Figs. 3, 5).

3. THE MALVERN NAPPE: THE VISIBLE SUB-DIVISIONS AND THEIR DESTINIES

Groom, following Callaway, believed that the Malvernian of the axis had been upthrust into contact with the Silurian to the west; But nature, according to the present writer, had worked in quite a different way. Though so fine a topographical feature, the axial mass of Malvernian is merely a slice, narrow and perhaps shallow, defined by step-faults downdropping east: a slice cut from the base of an Armorican nappe, and bounded below by a gently inclined thrust-plane. The exposed part of the nappe had involved the succession

deep into the Archaean. After the compressive stresses had folded the Palaeozoic and Pre-Cambrian rocks, the thrust-plane developed and variously cut them away from the Coal Measures down, judging from borings near Moreton and Burford, and as far as the Cambrian in the part available to observation. On the site of the Malvern Hills and far around, this thrust had brought from the east a local geological record on to the top of the truncated 'record' of the country; truncated here at levels in the Silurian and Cambrian, effecting thus a widespread duplication. Opposite the Hereford Beacon, the Pre-Cambrian constituent of the nappe included not only Malvernian but also the Warren House Series of volcanics. The present limitation of this series to this spot may be due to a local low position of the thrust-plane, which is indicated for the ground to the west by the persistence of the thrust Malvernian, west of the axis.

The thrusting would be the culminating effect of the Armorican compressive stresses, so far as the Malverns are concerned. These stresses had effected much folding and fracture, and the overturning of the folds beneath the transported mass; but, geologically speaking, it had been effected rapidly in the zone of fracture, not in the zone of flow, for the Palaeozoic rocks are nowhere cleaved.

It would be of considerable interest if the former extent of the thrust mass or masses could be determined. The close association of overturning of the Silurian and Cambrian beds with the outcrops of the thrust-planes in the cases of the Hereford Beacon and Chase End masses of Malvernian respectively, suggests that, in this particular movement where overturning is not associated with any considerable mass of Malvernian, such a mass was formerly not far above, but has been removed. The probability of this being so is greatly increased where small areas of Malvernian (or Cambrian) occur. Groom, it is true, referred all such masses to upthrusts of the Malvernian (or Cambrian) from below. But the way they are bounded makes it much more probable that they have come from a previously overlying and overthrust mass, and have been emplaced by tensile, not compressive, stress. For it is impossible to envisage the upthrusting from below as a product of widespread tangential compressive stress; whereas, thanks to gravitation, downdropping from above is quite a normal result of tensile stress.

The same applies also to the strips of Cambrian and Silurian among the Malvernian. Take, for example, Groom's sections (1899, figs. 10-13, 15). In figs. 18, 19 and 20 in the same paper, Groom gives his 'theoretical reconstructions' of the sections across Raggedstone Hill, Midsummer Hill and the Malvern Tunnel; he regards the inclusions as closely compressed infolds into the Malvernian. But simple normal faults, produced under tension, are much more probable, especially as well-preserved Cambrian and Silurian fossils are described as occurring in several of these inclusions. For, with the

mode of origin of the Palaeozoic inclusions envisaged by Groom, the fossils would have been sheared beyond recognition.

On the principles above enunciated, the thrust-plane carrying both the Malvernian and the duplication of the geological record had, west of the main axis of existing Malvernian, an elevation *above* the present country rocks; and it had, perhaps, the least elevation above the present surface, where the rocks are conspicuously overturned, as in the Abberley and Woodbury Hills, though there is no certainty of this. This thrust-plane has a lower level under Hereford Beacon and is lower still under Chase End Hill. Its position and slope can be determined at both these places. The railway tunnel indicates a further lower level under that site; and the presence of the Warren House Series opposite the Hereford Beacon rather suggests that these rocks may overlie the Malvernian, which would here be correspondingly depressed. The eastern boundary-fault drops the plane to depths still further beyond our ken; and we can well believe that it continues to descend eastward. P. E. Kent (1949, p. 95 and pl. 2) estimates that the upper limit of the Palaeozoic rocks descends here to a basin more than 3500 ft. below sea level! If we accept this figure and add to it an estimate of the thickness of the Palaeozoics, we reach a figure for the depth to the Pre-Cambrian? sediments and volcanics; below these and the Malvernian, we have the local geological record!

If the two faults, bounding the Malvern axis, are in origin of the same character and age, to what age shall we assign them? Groom made one Armorican, originating under compressive stress, the other Tertiary, due to tensile. The newest rocks, cut by the western fault, are May Hill Sandstone; whereas the eastern fault cuts Keuper Marl, and would seem to have had considerable movement in the Tertiary. But against a Tertiary *origin* of the faults is the fact that, already before the deposition of the Haffield Breccia, there had been enormous denudation of this Malvern-Abberley region. The Haffield Breccia directly overlies part of the overturned Silurian in the Abberley Hills, which, as is suggested above, may have been previously covered by Malvernian, etc. Also, according to Groom, it overlies Silurian in the Teme Valley at Knightwick, where it is covered without discordance by Upper Bunter Sandstone and so may be partly Triassic in age. Again, at the south end of the Malverns, we have the Haffield Breccia adjoining and at the same level as the Chase End thrust-plane, which carries Malvernian apparently without any other fault between them.

It would appear, therefore, that, already before deposition of the Haffield Breccia, the nappe had suffered enormous erosion, and that, unless the Malvernian of the axis had been already dropped into place, it too would have been removed, or at least extensively denuded. The conclusions inevitably follow that the Armorican compressive stress had been succeeded and replaced by tensile stress in the same direction; that, in this way, the Malvern axis had already

secured its preservation by being dropped, probably to its present relation to the country west of it; and that the eastern boundary-fault had at the same time come into existence and had received the *greater* part of its throw! On this, however, there must have been renewed movement at a later time, which was probably Tertiary. If it be true that the axis owes the emplacement of its rocks to two quite distinct movements, one due to compressive and the other to tensile stress, it is clear that the Hills owe their present existence to the second rather than the first; for, had the strip of Malvernian not been dropped into place, it might have been entirely removed by denudation; and had that happened Hereford Beacon would probably have gone as well, because for long this must have been protected by the Malvern axis to the east of it.

The great steepness of the western boundary-fault has earlier been mentioned: it must have a very definite cause. Is it attributable to the great rigidity and peculiar situation of the Malvernian mass? The thrust wedge of Archaean rocks would be much more rigid than the Palaeozoic masses below and above it, and hence, when subjected to severe tensile stress, would tend to snap across its extension; and, in the subsequent settlement, its greater strength would favour retention of its shape.

The Malvern nappe represents the greatest Midland uplift of which we have evidence, for nowhere else do we find crystalline Archaean; and, though what we see was effected in the zone of fracture, the movements necessarily extended into the zone of flow. In the case of the thrust, this was beneath a region far to the east, but in that of the normal faults, deep beneath a much nearer district. Why we find Pre-Cambrian and coarsely crystalline Archaean in the thrust mass, instead of only Palaeozoics, might be attributed to the geological history of the Midlands before Armorican times. Its tale of strata is in marked contrast with that of the Welsh geosyncline. Limiting ourselves to the older Palaeozoics, which alone submit to comparisons, the thickness is somewhere near 6000 ft. for the Midlands as against 30,000 ft. in Wales. In the Batsford boring near Moreton-in-the-Marsh, the Upper Coal Measures directly overlies Silurian.

On this theory the hills of the 'axis' are carved from the basal strip of the nappe within what is a mere splinter, $7\frac{3}{4}$ miles long, or a series of splinters of the Armorican earth-crust (see horizontal and vertical sections in Figs. 1 and 6).

Structures and movements so extensive would entail numerous stages and long time; and be accompanied by movements in other places. All three main sections—the earlier foldings, the great overthrusting and the normal faulting—would increase both surface gradients and denudation, and the products of the last would be reflected in stratigraphy elsewhere (see Wills, L. J., 1950).

The interpretation offered in this paper is still a theory; but now

that geophysical prospecting is so extensively practised, it is hoped that the area may soon be investigated. A thrust-plane below the Malvernian might exhibit a negative reflection from its surface.

The theory suggests a subdivision of the history into eight stages, as given in the following table, which was circulated on the occasion of the British Association Meeting at Birmingham, 1950, when the substance of this paper was presented.

4. SUMMARISING TABLE

Geological and Structural Evolution in the Malvern and Abberley Hills region.

STAGES	SYMBOLS	
Armorican Stages I-III	A I.	Folding of an extensive region under tangential, mainly E-W., compressive stresses.
	A II.	Overthrust from east to west on to this region of a mass comprising folded Palaeozoics (Cambrian to Carboniferous) and Pre-Cambrian on the Archaean igneous and metamorphic 'Malvernian', under tangential compressive stress. This extensively duplicated the succession over the Malvern-Abberley region and to east and west of it, and also overturned the rocks beneath it.
	A III.	Delimitation of the axial area of the Malverns (North Hill-Raggedstone Hill) by normal step faults (the eastern and western boundary-faults) downdropping east, under tangential tensile stress.
'Mesozoic' Stages IV & V	M IV.	Denudation, especially of the still uplifted western region, and extensive removal of the thrust mass from it, leaving perhaps only the very bottom in the Hereford Beacon and the Chase End masses. Denudation also of the axial mass from which apparently the Palaeozoics and much Pre-Cambrian and Malvernian were removed.
	M V.	Progressive burial of the whole region under Triassic, Jurassic and Cretaceous strata.
Tertiary Stages VI-VIII	T VI.	Post-Cretaceous elevation and uptilting to the west in the origin of Britain, initiating removal of the covering formations.
	T VII.	Late Eocene renewed movement down to east on the Malvern eastern boundary-fault.
	T VIII.	Continued denudation under Tertiary and Quaternary conditions.

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EXPLANATION OF PLATE 8

The Malvern Hills north of Little Malvern but looking north from the west side. The entrenchment, separating Herefordshire on the left from Worcestershire on the right, is well seen.

NOTE ON THE CORALLIAN ECHINOID *Pygurus hausmanni* (Koch and Dunker) FROM THE YORKSHIRE WOLDS

By K. A. Joysey, B.Sc., F.G.S., F.Z.S.

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SUMMARY.—A description is given of a large specimen of the echinoid *Pygurus hausmanni* (Koch and Dunker), a species rare to this country. The detailed morphology is discussed in relation to the mode of life and evidence is produced that this species lay partly buried on the sea-floor.

INTRODUCTION

DURING the Summer Field Meeting (1950) of the Geologists' Association in East Yorkshire, the party visited a quarry on North Grimston Hill, near Malton. The section is in Corallian rocks that are correlated with the Osmington Oolite Series of the Dorset Coast. In terms of the local succession, beds of the 'Urchin Dirt Beds' facies underlie the quarry-floor and outcrop in the road-section lower down on the side of the hill. The quarry itself contains Beds 5 and 6 of the succession on North Grimston Hill listed by Vernon Wilson (1933).

A large echinoid was collected from the quarry. This has now been identified as belonging to the species *Pygurus hausmanni* (Koch and Dunker, 1837, p. 38, pl. 4, fig. 3). The species was redescribed and figured by Thomas Wright (1878, p. 405, pl. 39, fig. 2; pl. 40; Suppl. p. 467) who listed the European localities from which it has been recorded. In England, the species has been found only in the vicinity of Malton in rocks of Corallian age. Most of the specimens previously found here have been crushed, because their large size made them particularly liable to damage.

It seems worth while, therefore, to place on record the discovery of another example of this rare species, for, although fractured and partly missing, it is uncrushed. The stratigraphical horizon of this particular specimen is more accurately known than of those previously recorded. A few minor deviations from Wright's description are considered to be within the range of variation of the species. The relationship between certain anatomical features and the mode of life is discussed.

DESCRIPTIVE NOTES OF THE SPECIMEN

Dimensions. Diameter	...	...	...	...	18.10 cms.
Height	...	...	...	...	3.56 cms.
Length of ambulacrum	...	...	...	...	9.10 cms.
Thickness of test (a) aboral	...	...	...	...	0.17 cms.
(b) oral	...	...	...	...	0.07 cms.

Description. The test is depressed, the aboral surface convex and the oral surface slightly concave. Sufficient of the ambitus is preserved to confirm that the urchin was almost circular in outline. The interambulacral areas are unequal as the ambulacra diverge from the apical disc at slightly differing angles.

There are 196 pore-pairs present between the apical disc and the ambitus. These pore-pairs are mainly of the 'dot-dash' pattern. The pores of the inner row are perfectly circular in the region of the apical disc and the ambitus, but are oval in the middle region of the ambulacral petal. The slits of the outer row attain a maximum length of 4 mm. in the middle region of the petal. They become progressively shorter towards each end of the petal and are reduced to circular pores on the seven ambulacral plates nearest to the ambitus. The uniserial condition of the pores in this region, as depicted by Wright (1878, pl. 40), is not borne out by this specimen. On the oral surface, only five pairs of minute circular pores are visible, due to matrix obscuring the rest of the surface.

A faint smooth line, devoid of any tubercles, marks the position of the perradial suture between adjacent longitudinal rows of ambulacral plates. The sutures between the interambulacral plates are very closely sealed and difficult to detect though, near the ambitus, a slight thickening marks their position.

The primary tubercles are distinctly perforate and each is raised on a boss above a sunken areola. The ambulacral plates of the aboral surface bear a variable number of primary tubercles. Because this is a large specimen, the maximum number of these tubercles is four, compared to the maximum of three shown by Wright (1878, pl. 39, fig. 2).

High magnification of the most perfectly preserved parts reveals that the 'close-set miliary granules', which Wright described from the 'inter-tubercular portion of the plates', also possess an areola. As the areola serves for muscle attachment, it seems likely that they bore small spines or pedicellariae. The septum between the slits of adjacent pore-pairs, bears a row of minute delicate granules. Wright describes them as a 'horizontal row of nine', but there are as many as seventeen between the longest slits in this specimen.

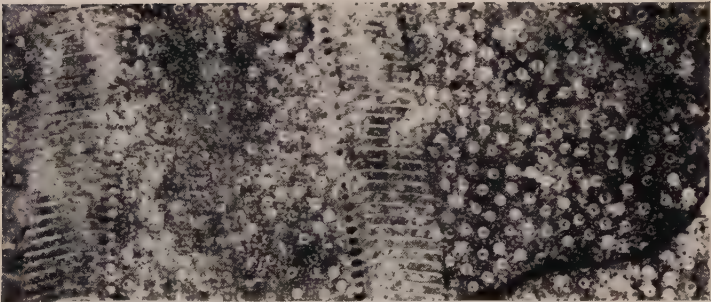
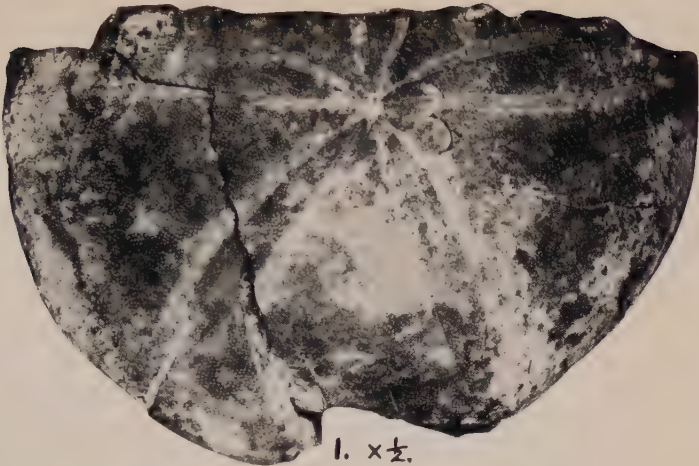
Mode of Life. The cross-section on the fractured side shows that the oral surface is slightly concave, the inner region being raised 5 mm. above the margin. The mouth is raised in this concavity, so that, at first sight, it does not seem unreasonable to suppose that *Pygurus* lay flat on the sea-floor, when one might expect the peripheral areas of the underside to be covered with large numbers of tubercles for the attachment of locomotary spines. In order to investigate this problem further, a small area of the underside was prepared, and it was found that the tubercles are far more numerous than are shown in Wright's text-figure (1878, Suppl. p. 467). The

interambulacra are slightly convex and bear many tubercles on the swollen area, whilst the borders adjoining the ambulacra bear more sparsely distributed larger tubercles. In areas of maximum concentration, the tubercles are so closely packed that the surrounding areolae are forced into a polygonal pattern. Now, a similar concentration of large tubercles is found on the oral surface of those genera which are believed to have crawled on the surface of the sea-floor. For example, this condition occurs in the genera *Pygaster*, *Holactypus*, *Conulus* and *Discoidea*, in all of which the ambitus marks the position of an abrupt change in the size and concentration of the tubercles. In contrast, those urchins, which burrow in the sea-floor, are usually covered with large numbers of tubercles both on the oral and aboral surfaces.

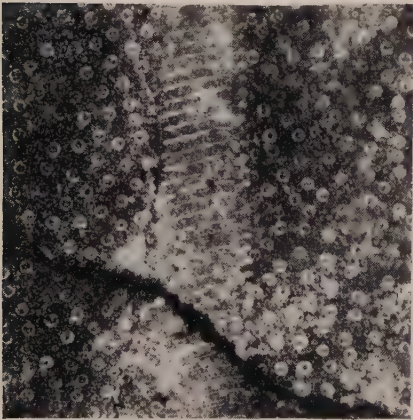
Pursuing the problem further with *Pygurus hausmanni*, the ambitus is densely covered with primary tubercles which are larger than those on the main interambulacral areas of the aboral surface. They are orientated so that the axis of the tubercle is inclined, as though the spines which they supported lay obliquely to the test. The sunken areola, which served for muscle attachment, is asymmetrical, being wider towards the aboral side. This is evidence that the larger muscles were on the upper side, and, therefore, the most powerful sweeping-action of the spines would be in an upward direction. As these spines would throw the bottom-sediment over the edges of the ambitus, the action would tend to bury the marginal areas of the aboral surface.

It seems, therefore, likely that, in life, this species lay part buried, the lower surface being completely concealed by sediment. The nature of the test itself supports this view, for the oral side is less than half the thickness of the aboral. The slits of the outer row of pore-pairs indicate that the tube-feet of the aboral surface were adapted for a respiratory function. These slits become progressively shorter in length towards the ambitus, and, in the marginal area, which would be buried, they are reduced to circular pores. It seems that the end of the petaloid portion of the ambulacrum indicates the extent to which sediment was liable to cover the upper surface during life.

In conclusion, a comment on sea-bottom conditions at Malton, during Osmington Oolite times, would not seem out of place. The limestone within the urchin is very much more shelly than the matrix-block adhering to the underside. As the inside shelly material is all fragmentary, it does not appear to be the remains of small shellfish which crawled into the dead urchin. The shell-fragments must have been washed inside whilst the urchin lay on a substratum of shell-débris—perhaps the normal habitat in life. Then, current action must either have moved the urchin to a less shelly matrix, or, alternatively, have washed away the surrounding shelly material. In either case the disturbance must have been so slight that the movement was not over any great distance or the urchin itself would have been destroyed.



2. x 3.



3. x 4.



4. x 4.

Photo { M. C. Kennard
D. G. Wright

I should like to express my thanks to Mr. K. Seal, who gave me the specimen, and to Professor S. E. Hollingworth for his helpful advice and criticism on the preparation of the manuscript.

EXPLANATION OF PLATE 9

- Fig. 1. *Pygurus hausmanni* (Koch and Dunker). Osmington Oolite, North Grimston Hill, near Malton, Yorkshire. Aboral surface, $\times \frac{1}{2}$.
„ 2. *Ibid.* Details of pore-pairs in the widest region of the ambulacrum, $\times 3$.
„ 3. *Ibid.* Minute granules which probably served for the attachment of pedicellariae between the slits of the ambulacral pores, $\times 4$.
„ 4. *Ibid.* Reduction of the slits of the outer row to circular pores, in the region of the ambitus, $\times 4$.

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THE RIVER YSTWYTH, CARDIGANSHIRE : A GEOMORPHOLOGICAL ANALYSIS

By E. H. Brown, M.Sc., F.R.G.S., F.G.S.

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SUMMARY.—Evidence of several stages in the geomorphological evolution of the Ystwyth Valley has been found in an intensive field study of the long profile and valley-form. Along the lower Ystwyth, valley-benches have been mapped and their heights measured. From these, tentative stages are deduced. The long profile of the river has been accurately levelled. From extrapolations of the graded segments, using logarithmic curves, possible base-levels have been calculated for three stages. The third source of evidence has been the tributary-profiles which were surveyed with the aid of an aneroid. This evidence confirms the stages deduced previously.

1. INTRODUCTION

THE landscape of North Cardiganshire may be resolved into a series of ancient erosion-surfaces at various heights and in varying degrees of preservation (Brown, E. H., 1950); the lowest is

the Coastal Plateau which reaches the present coast-line in a series of magnificent cliffs. The average fall is from 500 ft. to sea level within half a mile; in places there is a sheer drop. These surfaces are now heavily dissected by river-action.

In the Llyn to the north and to the south, in Pembrokeshire, erosion-surfaces lower in altitude than the Coastal Plateau are to be seen. The absence of these lower surfaces in North Cardiganshire may be due to marine erosion into the less resistant Palaeozoic rocks. Thus it is from the rivers of North Cardiganshire that information concerning the later stages in denudation may be sought. A detailed study of the long profile of the Ystwyth and the valley-benches within the lower part of the valley, has been made. This was supplemented by a survey of the profiles of the main tributaries.

The River Ystwyth rises in the boggy areas on that part of the high plateau which overlooks the Upper Wye Valley from the south.¹ In its upper reaches the Ystwyth is overshadowed by the tributary Afon Diluw. Quite obviously these streams belonged at some unknown period to the Elan-Wye drainage-system. They have since been captured by headward erosion of the middle Ystwyth. A broad marshy drift-filled gap between the Ystwyth and Elan indicates the former river-course. The old coach-and-drovers road follows this gap into the eastward-flowing system down to Rhayader. The marshy floor of the gap is the watershed between the Cardigan Bay drainage and the Bristol Channel streams at this point.

Below the gap and the Afon Diluw junction, the course of the Ystwyth is almost a straight line as far as Llanafan. Below Ty-Mawr this middle stretch is guided by the Ystwyth fault. The valley is everywhere deeply incised into the plateau surface, contrasting with the mature open aspect of both the Diluw and Ystwyth in their headwaters. Tributaries in this part of the course are short mountain streams tumbling down the valley-sides into the narrow main valley. Between Cwm Ystwyth and Pontrhydygroes, the valley is less deeply incised. The valley-sides are less steep, probably because they are formed by the less resistant strata of the Myherin and Lower Rhuddnant Groups. The tributaries are longer (cf. Pwll Peiran, Nant Gau and Nant Milwyn). The narrow, steep-sided valley-form is found again below Pontrhydygroes for a further $3\frac{1}{2}$ miles. Then it suddenly opens out on to the much wider, flatter valley-floor of the lower Ystwyth. The river leaves the fault-line which may be traced WSW. into the Wyre Valley and turns to the NW., flowing between a series of fluvio-glacial terraces on an otherwise flat floor, ranging in width from a few hundred yards to over three-quarters of a mile. In this lower part of its course, the valley-sides rise steeply from the flood-plain to the height of the prevailing erosion-surface—that of the Coastal Plateau. The course of the river has been interfered with

¹ Reference should be made to Sheet 127 New Popular Edition of the O.S. one-inch map.

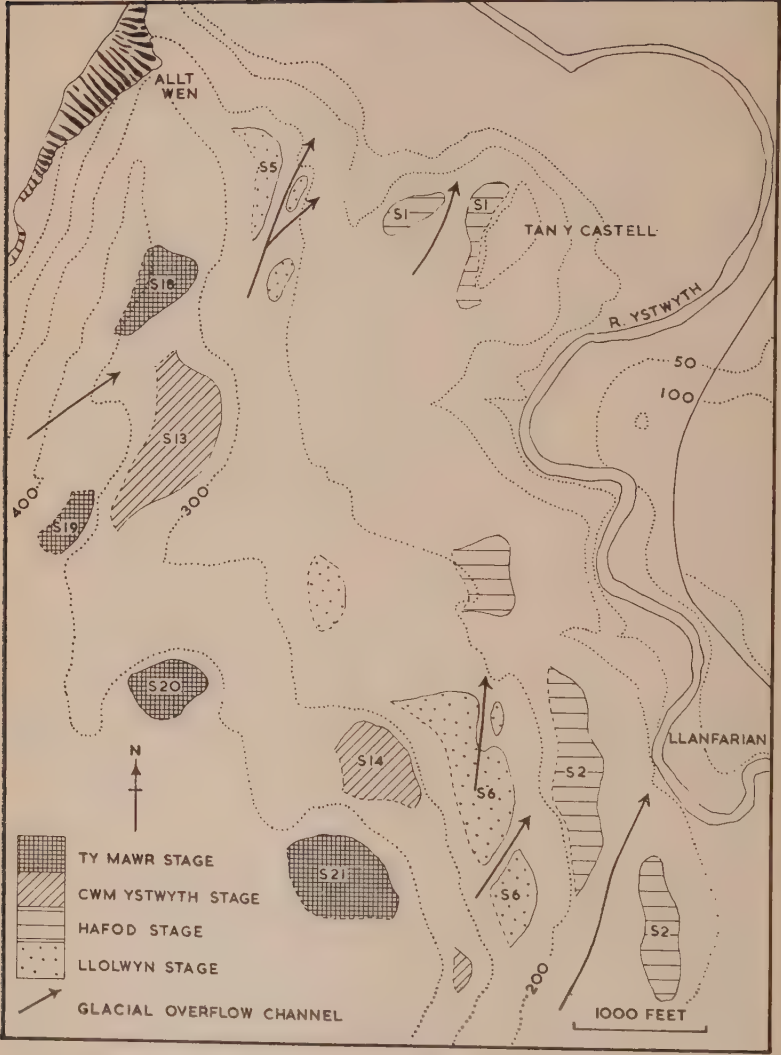


Fig. 1.—Valley-benches near Llanfarian (Pentre Bont).

during the building of the railway. Its mouth has been diverted to help in the formation of the harbour of Aberystwyth, and a process of river-control is still carried out to prevent the encroachment of the meander-loops in the lower Ystwyth on to the flood-plain fields.

At two points in this lower section, the river is confined to a narrow channel with bed-rock exposed in the river-banks. At Crosswood the river impinges upon the south bank and flows across outcropping grits and shales. Between Llanrhystyd Road Station and Rhydyfelin, the river flows in what may be meanders incised first into fluvio-glacial material and then below that into the Aberystwyth grits. Above this narrow portion, the river meanders over a waste of pebbles flanked by fluvio-glacial terraces; below, the flood-plain is well-developed and there are no terraces to confine the river.

2. THE VALLEY-BENCHES

The valley-benches along the lower Ystwyth from Pont Llanafan to the sea were investigated in the field and their extent was plotted on 6 in. field maps (Fig. 1). At the same time the height of the valley-bench was determined, using a surveying aneroid recording to one foot. The heights of both the leading edge of the facet, i.e. that edge nearest the centre of the valley, and the rear edge, were measured in this way. By frequent checks on bench-marks, corrections could be made to the aneroid-reading to allow for changes in atmospheric pressure. The heights are therefore accurate to within at least ± 3 ft.

The valley-benches have been plotted in section-form (Fig. 2), each bench being represented by a quadrilateral, the base of which represents the leading edge of the facet. The rear edge is represented by the top and the range of altitude of the facet is given by the lengths of the sides. The length of each quadrilateral is the length of the valley-bench measured along a line parallel to the centre line of the present valley. Each facet is numbered and designated N. or S. according to the side of the valley on which it is found—either north or south. The quadrilaterals are, in fact, orthographic projections of the valley-benches on to a vertical plane extending above the middle line of the valley.

It is hoped that, by careful observation in the field, any benches, other than those of polycyclic origin, have been excluded. The actual form of the facet varies. Some are almost flat and the rear slope rises abruptly, when the location of rear and leading edges is a simple matter. This form appears diagrammatically as a low quadrilateral although in the field it is more convincing than the facet which appears diagrammatically as a strikingly high quadrilateral. The most common form of facet is that which appears as a flattening of the valley-side gradient. The sharply-defined leading edge of the theoretical valley-bench, which may have existed in the initial stages, has long disappeared. Sub-aerial weathering has converted the sharp

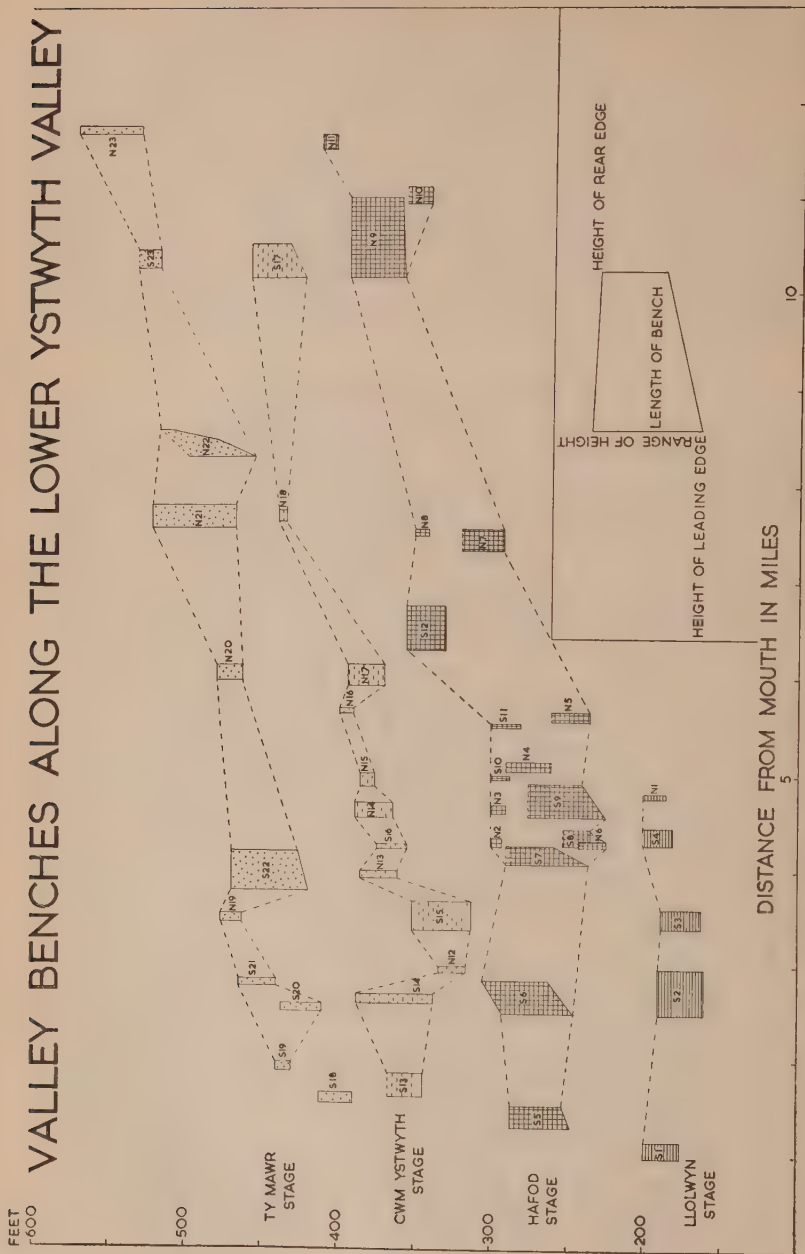


Fig. 2.—Valley-benches along the Lower Ystwyth

break at the leading edge into a gently convex slope; the choice of leading edge on such a facet is a question of personal interpretation and judgment. It is impossible to make the choice whilst actually standing on the valley-bench as the change in gradient is so slight. Instrumental measurement was tried and it was found that, by getting a profile view of each facet, the leading edge could be more simply determined. The flattest portion only of the breaks in slope were taken for purposes of measurement.

The determination of the rear of each facet was more difficult but probably of less consequence if in error. The arbitrary choice of some point in a smooth concave curve was made where there was no definite guide. Soil-creep and glacial deposition makes the accurate location of the rear edge impossible in many cases.

In the interpretation of the valley-bench diagram, certain essential points must be held in mind. The valley-benches, being remnants of some part of a valley-floor and sides of a past stage, will inevitably rise in height upstream. The gradient of the valley-floor is an unknown quantity. It is not necessarily the same as the present gradient of the river at that point. If it were, then the assumption is being made that volume and load are identical for both the present and the past. This is extremely unlikely. The present overall gradient of the Ystwyth is 1700 ft. in 27 miles and it falls the last 200 ft. in 10 miles. If past gradients were anything like the present, then this rise of the valley-benches upstream cannot be ignored.

The second consideration is that the valley-benches are at an unknown distance from the position of the river at their particular stage. Very steep facets may have been parts of the valley-side and, therefore, farther away from the river-level at that time than were flatter valley-benches now occurring at somewhat similar heights. Theoretically the flatter facets should be lower in height than the steeper of a similar stage. The former are remnants of the old valley-floor.

A further point in the technique of interpretation enables the facets of the various stages to be sorted out from one another. On the facet-diagram, at any point along the valley, a gap will exist between the leading edge, as represented by the bottom of a quadrilateral and the rear edge of the facet next below it. This gap represents the steep portion of the valley-side between valley-benches. The gap, when traced upstream, will rise in a similar manner to the river-profile at that stage. The gap is a zone within which the since-departed river-bed used to be. By tracing the gaps between stages on the valley-bench diagram, a rough estimation of the profile of the river at the various stages can be obtained. If the gaps can be traced downstream far enough, an approximate value for the base-levels for each stage can be obtained.

Weathering and downhill movement of material, subsequent to the formation of the benches, will tend to close the gap. The rounding-off

of the leading edge and the accumulation of hill-wash, masking the rear edge together with either deposition or erosion by moving ice, all tend to obliterate the gap.

(a) Llolwyn Stage—Approximate height at present coast, 150–75 ft.—This stage is represented by the five facets shown on Fig. 2. There is a marked gap of at least 25 ft. between this stage and the one above. As this is the lowest of the stages, there is no guidance in a downward direction. Below this stage only fluvio-glacial terraces are found. Four of the five facets are on the south bank of the river. S.1 and S.2 are broken by what seem to be small glacial spillways (Fig. 1). S.1 is on the western side of the camp, Tan-y-Castell. S.2 is developed either side of the Cardigan road, half a mile SSW. of Llanrhystyd Road Station. The house, Aber Llolwyn, stands on part of this valley-bench. S.3 is being undercut at the present time by the river where it impinges on the south side of the valley at the spot-height 162, $\frac{1}{2}$ a mile SW. of Aber Llolwyn, on the Llanilar road. This road rises from the river, at Llanfarian (Pentre Bont), on to the surface for a few hundred yards and then descends on to a fluvio-glacial terrace which it follows to Llanilar. S.4 is a small but well-developed bench just above road level at Abermâd. N.1 is a much smaller break in slope on the north side of the valley. A river-level of 150–65 ft. at the present time is suggested for this stage to which the name Llolwyn is given. There is no evidence of the Llolwyn Stage farther upstream; it may be masked by the fluvio-glacial deposits which rise in places in 50-ft. river-cliffs above the river itself.

(b) Hafod Stage—Height at coast 220–50 ft.—The gap between this stage and the one below is well-marked; it varies between 50 and 25 ft. S.5 is found on the valley-side overlooking Tan-y-bwlch. A narrow but deep overflow-channel, probably of the marginal type, has been cut into it, and at the seaward end this branches into two separate arms. The bench is thus cut into three portions but the flat summits of the two outlying portions are convincing evidence of its erstwhile unity. In a similar manner, a channel has been cut across the southern end of S.6. This facet is probably the freshest-looking one that appears in the Ystwyth Valley. Six hundred yards long by 150 wide, there is a very abrupt slope up in the rear and the leading edge is well-defined (Fig. 1).

The group of facets, S.7, 8, 9, 10 and 11, N.2, 3, 4, 5 and 6 are confusing fragmentary evidence of this stage. None is of very great extent and the range between each is quite large. N.4, although small, is well-developed. It is the flattened end of a spur which juts out into the valley; above it is the Castell, south-east of Ty-isaf. The solid rock outcrops in the leading edge and more reliance is placed in this facet than in the rest of the group. S.11, like N.4 on the opposite side of the valley, is a small, flattened spur which, when viewed in

the field in profile, is much more self-evident than is indicated by map or diagram.

S.12 is a well-developed, gently sloping surface just upstream of the village of Llanilar. It is possible that it belongs to the stage above. However, it has been excluded because the gap above it is large. N.7 is a better valley-bench. It occupies a position on the eastern spur between the Ystwyth and its north-bank tributary, the Afon Llanfihangel. N.8 is a small facet above N.7 on the same spur. East of these benches, the valley-sides, both north and south, are smooth and very steeply inclined from heights of over 400 ft. to the general level of the valley-bottom.

The valley widens beyond this smooth-sided stretch which is about two miles long. Beyond Crosswood the much wider valley is again closed by an extensive surface a mile wide rising to a height of 400 ft. The village of Llanafan is sited at the back of this surface. Behind the village the land rises abruptly to heights of over 1000 ft. up to the middle plateau. On examination this Llanafan block resolves itself into a surface whose leading edge is 364 ft. O.D., but the back edge hardly exists, as there is a gentle slope up to 400 ft. which may be the height of the Cwm Ystwyth Stage at this point. The height of the Llanafan surface indicates the general rise in height of the Hafod Stage when traced upstream. N.10 and N.11 are minor facets on this block.

The Hafod Stage falls to a level of between 220 and 250 ft. at the present coast—the higher limit being that which would occur if the doubtful facets were excluded, the lower limit being one in accordance with all of them but too low for the best.

(c) Cwm Ystwyth—Height at present coast 315–40 ft.—The gap at the seaward end of the valley, between the Hafod and Cwm Ystwyth valley-benches, is very narrow. At its minimum it is no more than 5–10 ft. This narrowness is largely due to the two facets N.12 and S.15. The latter is, from superficial appearance, a true valley-bench. N.12 is less satisfactory. The evidence for this stage is nowhere well developed, but it does appear as a group of facets quite distinct from the stages above and below. S.13 and S.14 appear in that veritable staircase of valley-benches on the south bank, between Pentre Bont and the sea (Fig. 1). S.13 is even noticeable on the 1 in. map; it causes the bulge eastwards of the 300 ft.-contour beneath the 'y' of 'Llanychaiarn'. S.14 is denoted in part by the plantation overprinted by the 'P' of 'Pentre Bont'. S.15 is found on the valley side behind Aber Brwynen. S.16 is a small but well-developed bench which turns and slopes upwards into the small tributary-valley through Tan-y-Graig. The earthworks, Castell, mentioned in connection with N.4, are sited on a higher bench on the same spur. This forms N.15; N.14 is well-marked and convincing in the field. The leading edge is easily determined as the facet is fairly flat. The rear edge is less easy to pick

out as the facet passes upwards into a smooth concave curve which becomes almost vertical. N.17 is a flattened spur north of the river at Llanilar and it is paired by N.18 on the spur above Glan Ystwyth. N.18 might conceivably belong to the stage above; however, if it is included in that stage, the gradient of the gap would be very slight compared with the other stages. S.17 is a facet on the lower eastern slopes of Gaer Fawr just above the railway. Across the river, the summit-level of the Llanafan block is 400 ft. which might represent the height of the Cwm Ystwyth Stage at this point.

(d) Ty-Mawr Stage—Height at present coast 400 ft.—The gap between the Cwm Ystwyth and Ty-Mawr Stages is well-defined and there is only one anomalous facet. This is the one farthest downstream and it is in an important position when an approximate base-level is decided upon. The approximate level chosen is 400 ft., but it will be seen that S.18 does not fit in with this reckoning. It is a small facet but ranges in height between 389 and 411 ft. O.D. S.19, 20 and 21 are the three highest facets in the amphitheatre of valley-benches behind the cliffs of Allt Wen. S.22 is a marked feature behind Tan-y-Graig. The reservoir is on its surface. The latter may be traced up the valley of the Mâd and would seem to be represented by several isolated summits rising to just over 400 ft. at the junction of the Mâd with the Ystwyth.

At several places on the north bank, there is a flattening at the critical height but the facets are not large enough to be mapped. N.19 is one such facet which is larger than the majority; it is to be found above Ty-llwyd ranging in altitude between 463 and 473 ft. above O.D. N.20 is this stage developed on the same spur as N.17. The slope of this facet is quite considerable, suggesting that it is a remnant portion which was away from the centre of the valley at the Ty-Mawr Stage. When seen in profile it is very striking.

The almost isolated hill of Pen-lan-isaf is etched by N.21 and N.22, two examples of valley-benches at this stage. N.21 is on the spur at the western end above N.18, N.8 and N.7. N.22 is a true valley-bench at the eastern end. S.23 is a similar bench on the side of Gaer Fawr above S.17. N.23 is a flattened spur at the point where the Ystwyth Valley narrows again. For over three miles upstream of this point, the valley-sides are steep and smooth. If, as is quite likely, this stretch has been moulded by ice (it has the typical U-shaped section) then the evidence of previous stages will have been either totally destroyed or so modified as to make it invalid.

3. THE LONG PROFILE

It is the middle section of the river which is of greatest interest in the analysis of the stages in the geomorphological evolution. As it is precisely this section which is in part fault-guided, a more detailed study of the relationship between the river and the underlying

geology is necessary. The Ystwyth Fault trends a little south of west and the middle stretch of the Ystwyth is closely related to this fault (Jones, O. T., 1935). Above the Cwm Ystwyth mine, in the neighbourhood of Ty-Mawr, the fault veers into an E-W. direction, passing out of the Ystwyth Valley into the Upper Elan. The line of the Ystwyth below Ty-Mawr is, however, continued above the farm so that not all of the middle stretch is fault-guided. It may be that a shatter-belt, other than that due to the Ystwyth fault, controls the direction of this upper straight portion of the valley.

Only in two localities is the fault known in detail; a brief description of these will be given. The extensive lead mining in the Cwm Ystwyth mine, about 1 mile upstream from the settlement of that name, has revealed the presence of the Ystwyth Fault (Jones, O. T., 1922, p. 17). The miners termed it the 'soft ground', i.e. the shatter zone of the fault. Levels, driven into the north bank from Pugh's Shaft, pass through this fault-zone within 200 yds. of the entrance. The Ystwyth at this point does not follow the fault in detail. Its present course is some 200-300 yds. away to the south. Downstream the fault is found north of the river for at least a further half mile.

In the neighbourhood of Pontrhydygroes the main fracture-belt passes through Maen Arthur Wood whilst the Ystwyth makes a slight detour following, in part, another fault-line. A few yards below the bridge at Pontrhydygroes, a 6 ft. band of calcite, thought to indicate the line of the fault, outcrops in the bed of the river. Still farther downstream, disturbed beds in a north-bank tributary are thought to be due to the Ystwyth fault, again to the north of the present river.

Elsewhere in the valley, the precise location of the fault is not known. It would seem, therefore, that, in detail, the river is not fault-guided. That the general line of the valley is so guided, is beyond all doubt, but the stream itself has lost contact with the fault at several points. It may be that the river has adapted itself to branches of the main fault which are not easily traced. Whatever the answer, it has an important bearing upon the form of the long profile of the Ystwyth. Two possibilities need to be considered:

(1) The valley is fault-guided and the river is adapted to other, as yet untraced, fault-zones. If this is so, then any breaks in the gradient of the river within the fault-guided portion must be due to rejuvenation. They cannot be due to differential rock-hardness. Shattering along the fault-zone will make all rocks uniformly weak.

(2) The river, in detail, may have lost contact with the dominant structural element—the Ystwyth fault. There is no evidence to prove this conclusively. Where it is known that contact with the main fault-line no longer exists, it is still not certain that the stream is entirely independent of structure. But, accept-

ing this hypothesis, the Ystwyth must then be regarded as the same as any other river in which sharp changes in gradient may be due to rejuvenation features or differential rock-hardness.

Whatever the truth of the matter, the Ystwyth fault is no hindrance in the interpretation of the river-profile. If the river is truly fault-guided, then the knick-points can only be knick-points and the fault, far from hindering, simplifies matters considerably. If it is not fault-guided, the Ystwyth will behave like any normal stream.

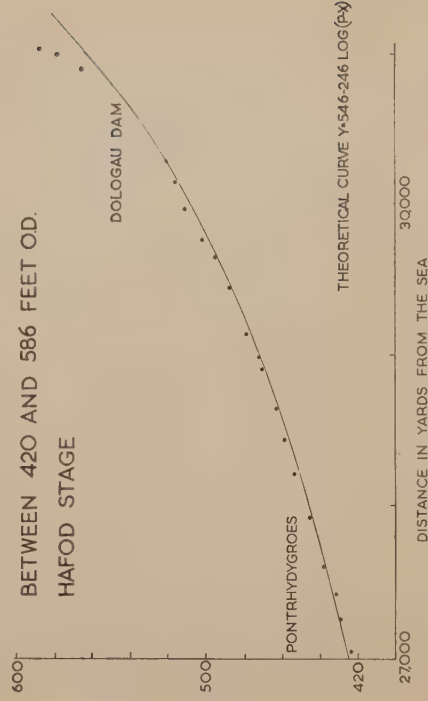
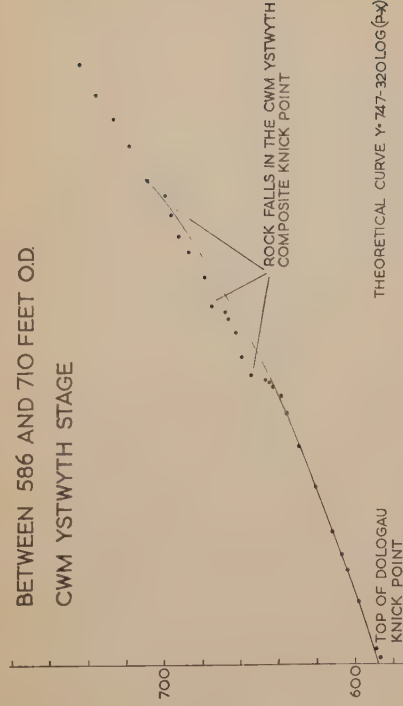
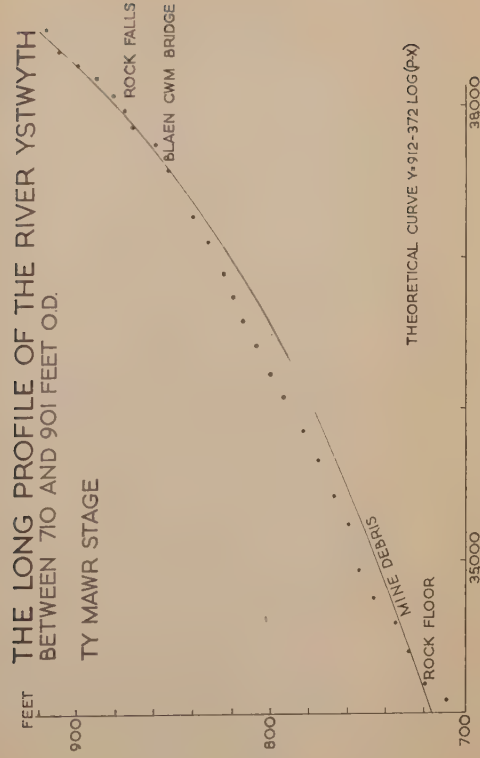
(a) **Measurement.**—Profile studies have been subjected to considerable criticism at various times. Miller has, in particular, made a constructively critical assessment of their value in landscape-evolution studies (Miller, A. A., 1939). O. T. Jones, after basing his Towy profiles on precise levelling, has severely criticised conclusions based on anything less arduously obtained (George, T. N., 1942, p. 129). After due consideration, it was decided that, if all elements of doubt concerning the validity of profile-measurements were to be set at rest, the profile should be levelled precisely, using a Dumpey Level and telescopic staff reading to one hundredth of a foot. This was analogous to the method used by K. C. Boswell (1946) in the measurement of the River Test. Although this involved much arduous work, especially in wooded stretches and where the river was incised into its bed, it was satisfactorily completed after nine months' field work. The help of two assistants for the levelling was invaluable. In all, 290 stations were used at an average distance apart of 150.4 yds. on the Ystwyth. The levelling of the Diluw in open moorland terrain was the most difficult task. It involved a further sixty-two stations at an average distance apart of 112.4 yds.

The river was levelled in sections of varying length. Each section was begun and finished on a bench-mark so that any closing error might be allowed for. As this type of error is cumulative, corrections were made proportional to the distance traversed in any one section. All distances were taken from six-inch maps. The water-level was the datum-line and all meanders were followed. Corrections were made for changing water-level and all heights are reduced to a common date (June 1948). To follow either the river-bed or the flood-plain would have made the task impossible in such country.

The average correction for levelling errors was minus 1 ft. in $1\frac{3}{4}$ miles; that for water-level changes was never more than 0.6 ft.

(b) **A general description.**—The twenty-three miles of the river shown on the profile (Fig. 3) (only this portion is used in the present study) reveals several very striking features. The average gradient is approximately 50 ft. per mile. Between the twenty-second and twenty-third mile the gradient reaches a maximum of 210 ft. per mile. At its mouth the gradient is still considerable: 10–15 ft. per mile.

The profile is not a simple concave curve but consists of a series of



DOTS DENOTE POINTS AT WHICH HEIGHT HAS BEEN DETERMINED BY LEVELLING
THE CONTINUOUS LINE IS THE THEORETICAL CURVE

Fig. 4.—The long profile of the River Ystwyth.

small 'graded' portions separated by sharp breaks in gradient. It is at these breaks in slope on the profile that the solid rock outcrops in the river-bed. Active down-cutting is apparent at these points. Between these outcrops, along the stretches of more gentle gradient, the river flows for the most part on a bed of rounded pebbles, the diameter of which varies between eight inches and two inches. The breaks occur at 170 ft. O.D., between 310-420 ft., 530-590 ft., ca. 700 ft. and 900 ft. At all these points the river is engaged in cutting into the bed-rock. Each incision is less spectacular than the one downstream, except in the case of the gorge at Pontrhydygroes, which is by far the most magnificent. The break of slope just below Crosswood is the least significant on the ground. There are thus five breaks of slope separating six portions where the gradient is less steep and the river is not actively cutting into the bed-rock.

The significance of these breaks of slope is vital in the reconstruction of former stages in the river's history. Each fall in the level of the sea sends a wave of down-cutting into the drainage systems of the rivers. The speed of back-cutting will depend upon the amount of change in sea level and the type of rock into which incision takes place. The greater the fall in sea level, the faster will be the retreat of the wave of back-cutting from the coast. The less resistant the rock, the more rapid will be the retreat. The breaks in gradient shown on the Ystwyth profile are taken to be such knick-points or rejuvenation-heads. No evidence to the contrary has been found in the present work.

(c) **Extrapolation.**—The more nearly graded portions above each knick-point have been extrapolated to the present coast so that some estimation of past sea levels may be obtained. In order that more definition can be attained, this has been carried out on a mathematical basis following the methods of O. T. Jones (1924, p. 589) and J. F. N. Green (1936, p. 59). This has been thought preferable to one carried out by eye only. The steepness of the profile and the shortness of the remnants of previous stages makes any such extrapolation somewhat uncertain. The use of logarithmic formulae has its drawbacks. The initial assumption is made that a graded river profile attains the form of the curve $y = c - k \log(p - x)$ (the simplified curve used by J. F. N. Green and later by T. N. George (1942, p. 93) is preferred here to the more complicated form used by O. T. Jones).

It is quite obvious that the actual form of the profile will not be suited exactly by such a curve. But by determining the curve which best fits any of the remnants of previous stages then extrapolation can be carried out on a mathematically defined basis, and is therefore not open to personal errors. It is for this reason alone that the complications of the method are struggled with. There is no inherent accuracy in the method as such and none is assumed. The evidence

from the profile is compared with the other lines of evidence (e.g., valley-benches) before a stage is definitely recognised. However, the valley-benches already described are not used as guides in the extrapolation, which is carried out from the profile alone. To use valley-benches as guides would invalidate any coincidence of results between the two methods.

The criticisms of this method by Miller (1939) can be met in the present instance by a consideration of the precautions taken. The data, upon which the profile is extrapolated, is as accurate as is possible in such terrain. The extrapolations, although based upon short stretches of river, are themselves short (15.2, 17.6, 19.4 and 21.8 miles), and errors over these distances will not be of sufficient magnitude to invalidate the results.

(d) **420–586 ft.: Hafod Stage** (Fig. 4).—Below the bridge at Pontrhydygroes the gradient of the Ystwyth quickens and, after about $\frac{1}{2}$ mile, the river plunges into a rock-walled gorge and falls more than 80 ft. in just over $\frac{1}{2}$ mile. The incision into the bed-rock is almost vertical and the water-surface is inaccessible. Judging from the noise of the water as it plunges through the gorge, it cascades over a series of waterfalls separated by quiet pools. This spectacular feature is the rejuvenation-head associated with the wave of back-cutting, which was set in motion by the positive change in sea level after a relatively long still-stand represented by the graded stretch upstream of the bridge at Pontrhydygroes. The Ystwyth fault is seen in the river-bed (denoted by a very distinctive white band of calcite) just below the bridge. The extreme nature of the knick-point may be due in part to an anticlinal feature across which the river cuts at this point. But as less resistant strata are exposed in the core of the anticline, it cannot be due solely to this cause.

Above the bridge the river-gradient is much less. The profile is a relatively smooth concave curve. The valley-floor is still restricted but is not as narrow as it is below the bridge. The river swings from side to side on this 200 yd.-wide flat floor. The lateral swing of the river has not as yet completely removed the fluvio-glacial terraces which border the river in several places in the Hafod estate, on the north bank, and below Dologau. At the latter place, between 495 and 520 ft., the profile is slightly convex. This irregularity may be due to the superficial deposits which would seem to attain a greater thickness here than elsewhere downstream to the bridge. The terraces also suggest this explanation. The first outcrop of solid rock in the river-bed above the bridge is seen at a height of 520 ft. Upstream of this, the gradient increases rapidly and the river is incised into its bed between vertical rock-walls. Just above 526 ft. a dam, 39 ft. high, has been built and the river ponded back for the generation of hydro-electricity. Upstream of 565 ft., the gradient is still very steep and it does not slacken until the river is at 586 ft. This increased

THE LONG PROFILE OF THE RIVER YSTWYTH BETWEEN 710 AND 901 FEET O.D.

TY MAWR STAGE

FEET

900

800

700

SIRREB D
MINE

ROCK FLOOR

ROCK FALLS

BLAEN CWM BRIDGE

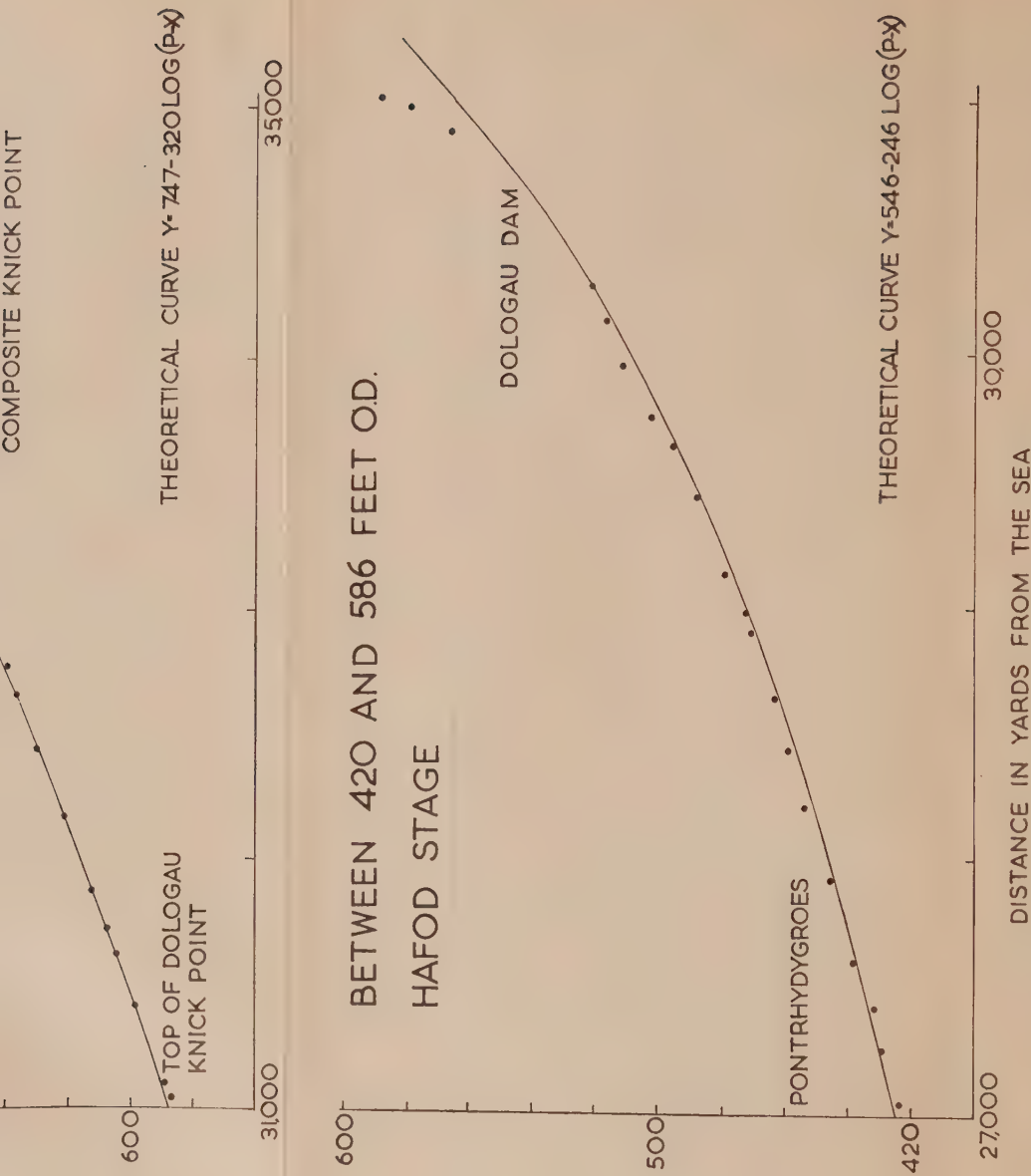
THEORETICAL CURVE $Y=912-372 \text{ LOG}(P-X)$

35000

38000

BETWEEN 586 AND 710 FEET O.D.
CWM YSTWYTH STAGE

700



DOTS DENOTE POINTS AT WHICH HEIGHT HAS BEEN DETERMINED BY LEVELLING
THE CONTINUOUS LINE IS THE THEORETICAL CURVE

Fig. 4.—The long profile of the River Ystwyth.

gradient above Dologau is another knick-point. It again consists, where not submerged in the artificial lake created by the dam, of a series of waterfalls and quieter reaches. The gradient of the river at this point can be judged from the fact that a dam, 39 ft. high, only creates a finger-like lake 363 yds. long. The remarkably abrupt change in gradient above the Dologau bridge suggests that here the rejuvenation-feature is accentuated by differential rock-hardness. The bed-rock, into which the incision is made, is a massive pale bluish mudstone. The exact line of the fault at this point is not known.

To this portion of the profile, i.e. between Pontrhydygroes and Dologau, a logarithmic curve was fitted. More attention was paid to the fit of the curve below the Dologau knick-point than to the fit in the knick-point itself at 526–586 ft. The curve $y = 546 - 246 \log(p - x)$ was found to fit the lower portion of the profile. The asymptotic point (the theoretical source) is at such a point so that $p = 32,580$ yds. In Fig. 4 the actual profile is represented by the dots of the heights determined by levelling. The theoretical curve is given by the continuous line. The fit is almost perfect below 526 ft., except at 516, 511 and 502 ft., where the actual profile is between 3 and 5 ft. above the theoretical curve. Here superficial deposits mask the true profile. The theoretical curve does not fit the Dologau knick-point. Above 540 ft. the two curves deviate markedly. Attempts were made to obtain curves, which gave a better fit at the head of the section, but it was found that this could only be done at the expense of the accuracy of the fit downstream. As the accuracy in fit in the downstream portion is of greater importance in the accuracy of the extrapolation, it was decided to use the curve given above.

The extrapolation of the profile at this stage is shown in Fig. 3. The height given at the present coast is 233 ft. The curve still has a gradient of five feet per mile at the coast. This, however, is not as great as the gradient of the present river at the same point (10 ft. per mile).

The extrapolation should pass through one of the gaps between the valley-benches shown in Fig. 2 and reproduced in Fig. 3. It fits the gap associated with the Hafod Stage at all points along the valley except between four and six miles from the sea. Note has already been made of these low facets; it is possible that outside influences, such as glacial action, have lowered them below the critical level. The coincidence is particularly good at S.5, and S.6, N.7 and N.9, N.10. These are considered, on other grounds, to be the more reliable facets. It will also be noticed that the extrapolation is strictly theoretical and there is no guarantee that a river-profile does approximate to a curve of the form used. Other curves of a non-logarithmic type could be fitted to the profile and would certainly give very different results.

The general coincidence of the two lines of evidence—(a) valley-benches, (b) extrapolated profile—strongly suggests the occurrence of a still-stand which has been termed the Hafod Stage. The height

of base-level at this stage cannot be accurately measured, as the precise location of the coast at that time is uncertain. From the form of the extended profile at the present coast, it would seem that, as its gradient is less than the present profile, the coast was in the vicinity of the present coast. Thus a base-level of approximately 233 ft. may be taken for the Hafod Stage.

(e) **586–710 ft.: Cwm Ystwyth Stage.**—Above the Dologau knick-point the gradient is much slacker (60 ft. per mile) but it is still greater than the gradient above Pontrhydygroes (42 ft. per mile). The meandering river is undercutting the glacial terraces into which it is incised. In this stretch the terraces are magnificent examples of their kind. They are flat topped and bounded by steep wooded faces. Where the river is actively undercutting, it is overlooked by lowering, crumbling river-cliffs. The gradient is smooth and uniform so that the profile is almost a straight line. Above 640 ft. the river is incised into solid rock and falls over several waterfalls, the top of these being at a height of 656 ft. Above this, for 350 yds., the gradient is very slight and low terraces occur on either side of the river. The pebble-bed of the river contrasts with the rock which is exposed above 664 ft. when the gradient increases again. Further rock-formed waterfalls are followed above 676 ft. by a quieter stretch where, however, bed-rock is exposed in the river. After a further stretch of about 200 yds., where the river is again on pebbles, the gradient increases yet again and the river falls in a series of cascades over the exposed bed-rock. Finally, above this point, 710 ft., the river is again flowing over pebbles and boulders with a much more gentle gradient.

Whereas, at Pontrhydygroes and Dologau, the break in gradient, forming the knick-point, was sharp and distinctive, at Cwm Ystwyth the knick-point is broken into a series of smaller falls separated by short flatter stretches. The total fall is approximately 70 ft., which is more than that involved at Dologau. The splitting of the knick-point may be due to an alternation of resistant and non-resistant rocks, the waterfalls coinciding with the resistant strata. Support for this suggestion is seen in the form of the valley-side on the south bank, where a ribbed form, caused by such an alternation of resistant and non-resistant rocks, is evident. The Ystwyth Fault is north of the river at this point and so the river is not fault-guided.

It may be that a composite knick-point is, in reality, a whole series of smaller knick-points whose existence is a significant part of the river's history. But even if this is so, it is impossible to apply an equation to such small stretches, some of them less than 200 yds. in length. However, it must be borne in mind that the extrapolation of the stretch—586–656 ft., i.e. that portion of the profile below the first section of the composite knick-point—would give a different result from that obtained by using the whole profile—586–710 ft.

The fitting of a curve to such a profile is less satisfactory than when

the knick-point is a single feature. When the knick-point is composite it is spread over a considerable length on the profile. In the present case the four subdivisions of the knick-point account for half the total length of the portion available for curve-fitting at this stage. This distance is only 3200 yds. in itself.

By fitting most carefully to the lower half of the profile, between 586 and 710 ft., and using the mean curve for the knick-point, the curve $y = 747 - 320 \log (p - x)$ was found to give the most satisfactory results. The asymptotic point is 20.75 miles from the sea. This fits the lower half with no deviation at all. The upper half of the curve is below the irregular line of the true profile but it fits at several points near the head of the knick-point. This would seem to be the most accurate curve it is possible to obtain with the composite knick-point.

This curve gives a height of 326 ft. at the present coast. It follows the gap between the Hafod and Cwm Ystwyth Stages reasonably well. N.12 and S.15 stand out as exceptions. It is within the bounds of possibility that they are facets belonging to the Hafod Stage and that the gap occurs above N.12 and S.15, i.e. the line followed by the extrapolated profile. The remainder of the valley-benches fit the curve in a manner which is strikingly convincing. The curve is roughly parallel to the Hafod Stage and therefore its residual gradient at the coast is still 5-6 ft. per mile. This stage has been given the name Cwm Ystwyth Stage from the locality of the knick-point. It represents a base-level of approximately 326 ft. O.D.

(f) **710-901 ft.: Ty-Mawr Stage.**—The profile between 710 and 901 ft. is less satisfactory from a morphological point of view than it is downstream. Just above the Cwm Ystwyth knick-point the profile becomes convex. This convexity is a feature of the river at several points upstream and makes curve-fitting difficult. The *débris* from the now derelict lead mine, a mile upstream from Cwm Ystwyth, has diverted the course of the river, pushing it over on to the south side. In addition the material dumped into the valley-bottom and river has raised the river-bed until the profile has a pronounced hump at this point. The convexity alone has a height of 6 ft. so that the rock-floor must be at least this depth below the present surface. There are reasons for supposing that it is even deeper than this. Immediately upstream of the mine, the river is thrust right over to the north bank by a large cone of *débris* which has been eroded from a corrie-like feature on the south side of the valley (see the 1 in. map). The river has cut through and around this glacial fill. Readjustment to the pre-glacial profile is so far advanced that there is little sign of convexity here at the present day. However, there is a convexity upstream which may be due to deposition when the cone of dejection did obstruct the river. Terraces left by the incision of the river into the fluvio-

glacial material, are a feature along the whole length of the river between the mine and Blaen-y-Cwm.

At no point above 710 ft., i.e. the top of Cwm Ystwyth knick-point, until the bridge at Blaen-y-Cwm, does the river reach the bed-rock. For over two miles boulders and pebbles cover the bed. At Blaen-y-Cwm the gradient steepens and the river falls over a series of rock-outcrops; the fall is between 12 and 14 ft. Above this point, the river is incised into the solid rock but the gradient is smooth and still steep. This continues until a height of 901 ft. is reached, after which the gradient slackens and the river loses contact with the solid rock-bed. Above this point the valley-floor becomes wider and the river is not incised. Between the bridge, at 850 ft. and 900 ft., is the knick-point related to the third stage. In form the knick-point is composite although not so complicated as the Cwm Ystwyth feature. The falls, which mark the lower end of the break in gradient, are caused by a more resistant rock-band, whilst the major portion of the knick-point shows no such composite form. It is a smooth, concave curve, probably worked out in soft shales.

It is obviously impossible to fit a curve of the form $y = c - k \log x$ to a river-profile which is, over much of its length, convex in form. The exact form of the rock-bed is unknown and so any curve used must be tentative. By fitting curves to the lower end where the bed-rock is exposed and above the convex part of the profile, an approximation to the true profile is obtained. After several unsuccessful attempts, the curve $y = 912 - 372 \log(p - x)$ was found to give satisfactory results. Here p is equal to 22.875 miles. It is a concave curve and can be seen to fit at the lower end and in the knick-point reasonably well. It is well below that part of the profile which is convex. If it is assumed that this theoretical curve approximates to the true river-bed, then the superficial material reaches a depth of 15 ft. at the maximum. This value does not seem to be unreasonable when the blocking of the valley by the cone of dejection, and more recently by the mine débris, are taken into account. Only borings through the superficial material can give any definite answer to this problem.

The curve, assumed to fit this section, extends to a height of 407 ft. at the present coast. It is virtually parallel to the two stages below. It is everywhere a little too high to pass exactly through the appropriate gap on the facet-diagram. S.18 is an anomaly as it is completely below the curve. It can be seen that all the extrapolated curves tend to be high in the gaps to which they should theoretically fit. This is probably due to the low gradient given by the particular curve $y = c - k \log(p - x)$.

The stage has been termed the Ty-Mawr Stage after the farm of that name on that part of the profile pertaining to the approximate base-level of 407 ft. O.D. at the present coast.

The generally parallel form of the extrapolated profiles at the

Hafod, Cwm Ystwyth and Ty-Mawr Stages and their low gradient at the coast, suggests that the contemporary base-level, and thus the coast-line, did not move far seawards of its present position.

(g) **170–420 ft.: Crosswood Stage.**—Just below the bridge at Crosswood, the gradient of the Ystwyth steepens. There is no obvious cause for this at the point where this increase occurs. Here the river is opening out on to the wide pebble-strewn wastes which are characteristic of the valley-floor from this point to the sea. Just above this point (the ford is on the actual break in slope on the profile) the river impinges on the south bank and is undercutting to form a river-cliff, along the top of which runs the road. In the bed of the river are exposed steeply-dipping grits and shales. Incision, to a depth of about 6 ft. into the solid rock, confines the river to a narrow channel.

Above Crosswood, the valley-floor opens out again; fluvio-glacial terraces are again prominent as the river swings southwards around the Llanafan block. At Pont Llanafan the river again finds its rock-bed where two meander-loops are incised into glacial material and then into the solid rock. This exposure of the true river-bed has no influence on the river-profile, which is a smooth almost straight line across this rock-outcrop. Upstream again the river meanders over the waste of pebbles until, at a height of 310 ft., its gradient suddenly increases at the bottom of the Pontrhydygroes knick-point.

The definite break in slope at the Crosswood ford may be due to the rock-bands exposed in the bed just above, or it may be yet another rejuvenation feature. The river has here left the line of the fault which is now three-quarters of a mile to the south. The rocks exposed in the river-bed are not massive and seem to be relatively easily eroded by the removal of the alternating bands of softer shales. If the break is to be interpreted as a knick-point, then it must be related to the valley-benches which occur within the first five miles from the sea. These facets (Llolwyn Stage) range between 160 and 200 ft. Extrapolation of the profile above Crosswood, parallel to the others, would give a base-level of approximately 100 ft. This is too low to fit in with the valley-bench evidence of S.1, S.2, S.3, S.4 and N.1.

(h) **Above 901 ft.**—Above the Cwm Ystwyth knick-point, the river gradient is very steep; the river is flowing on the rock bed strewn with boulders for most of the course. It has not been found possible to fit any logarithmic curve to this small steep portion of the profile. It is, however, suspected that this section of the profile is related to a base level approximating to the Coastal Plateau Stage.

4. PROFILES OF TRIBUTARY STREAMS

(Fig. 5)

The longer tributaries of the Ystwyth have been surveyed with an aneroid reading to one foot. By correcting for pressure changes, an

accuracy of ± 3 ft. is expected. Profile extrapolation has been carried out by eye, and distances were again taken from a 6-in. map.

(a) **Nant Paith.**—This north bank tributary rises on the Coastal Plateau and flows parallel to the Rheidol and the Ystwyth, midway between them. A natural continuation westwards of the Nant Paith forms the present mouth of the Ystwyth. The Ystwyth enters this broad, flat-floored valley from the south, after cutting through a barrier of glacial *débris* and incising itself in the grits and shales beneath. Nant Paith is 4.35 miles long and has an altitudinal range of 550 ft. The height of its present junction with the Ystwyth is 18 ft. O.D.

Only where erosion is most active, i.e. at knick-points, does the solid rock appear through the mantle of glacial material. However, there is reason to suppose that this mantle, at least along the rivers, is not very thick except in exceptional places, e.g. above Cwm Ystwyth mine. Nant Paith shows marked changes of gradient at 132, 202, 274 and 440 ft. In all cases there is incision below these points and widening of the valley-floor above. The incision is into solid rock. This suggests that these breaks of gradient are rejuvenation features. Other breaks of gradient, which look to be as significant as some of those mentioned, can be seen on the plotted profile, but there is no incision and valley-widening associated with them. Only the ones mentioned above are convincing in the field. Notes made in the field have been used in the assessment of the significance of these breaks in profile.

An extension by eye to the present junction of the Ystwyth suggests the following correlation:

(a) 132 ft.	Crosswood Stage
(b) 202 ft.	Llolwyn Stage
(c) 274 ft.	Hafod Stage
(d) 440 ft.	Cwm Ystwyth Stage

The most convincing is the Hafod Stage; the remainder can only be tentative estimates.

(b) **Nant Llolwyn.**—The most significant break is the one at 375 ft., which grades to a height of 350 ft., the Cwm Ystwyth Stage, at the present junction with the Ystwyth. Above 375 ft. the stream flows over an almost flat floor of boulder clay. Below 375 ft. it plunges down into a narrow gorge over a series of falls. There is a slight slackening of gradient and widening of the valley-floor above 310 ft. before the stream is again incised to fall over rock-outcrops, dipping steeply upstream. This flatter portion suggests a correlation downstream with the Hafod Stage on the Ystwyth. Yet a further widening of the valley-floor at 190–210 ft., where a cottage and two fields manage to squeeze into this narrow valley, suggests a link with the Llolwyn Stage of the Ystwyth. Below the two riverside fields, the

incision recommences and the stream again drops sharply in a series of waterfalls. The profile has not been measured below 170 ft.

Thus the Llolwyn carries evidence of knick-points at:

- | | |
|-------------|-------------------|
| (a) 375 ft. | Cwm Ystwyth Stage |
| (b) 310 ft. | Hafod Stage |
| (c) 190 ft. | Llolwyn Stage |

Of these the 375 ft. knick-point is the most certain.

(c) **Afon Fâd**.—The profile of this river is in general convex, but it is subdivided into a series of concave portions. There are strongly developed breaks in gradient below 170, 250, 350 and 425 ft. Extrapolations by eye to the present junction with the Ystwyth again suggests correlation with the stages tabulated below:

- | | |
|-------------|-------------------|
| (a) 170 ft. | Crosswood Stage |
| (b) 250 ft. | Llolwyn Stage |
| (c) 350 ft. | Hafod Stage |
| (d) 425 ft. | Cwm Ystwyth Stage |

(d) **Nant Ada**.—The profile of this stream is remarkably smooth; breaks in the general concavity are not easily picked out. In the field, incision below and the widening of the valley-floor above, suggests the existence on this profile of characteristic breaks.

The break at 150 ft., although striking, is not accompanied by any great slackening of the gradient. Above 190 ft. there is a widening of the valley-floor and this may be taken as the lower limit of that portion of the profile graded to the Crosswood Stage. There is some slight evidence for knick-points at 320 ft. (Llolwyn Stage), 395 ft. (Hafod Stage), and 466 ft. (Cwm Ystwyth Stage). The latter is the best developed on the ground. The meandering stream above 466 ft. suddenly increases in velocity and has cut through to the underlying rock floor.

- | | |
|-------------|-------------------|
| (a) 190 ft. | Crosswood Stage |
| (b) 320 ft. | Llolwyn Stage |
| (c) 395 ft. | Hafod Stage |
| (d) 466 ft. | Cwm Ystwyth Stage |

The 190 and 466 ft. knick-points are the most certain; the remainder look better in the field than they do on the plotted profile.

(e) **Afon Llanfihangel**.—This is the longest tributary of the Ystwyth. It rises on the Middle Plateau, descending very rapidly to a junction at 114 ft. O.D. with the Ystwyth. The profile is very irregular with many breaks which seem to have no geomorphological significance.

As the river rises at a height of approximately 1000 ft., evidence of the Coastal Plateau Stage may be expected. A sudden increase in gradient and incision to the underlying rock-floor at a height of 830 ft. may represent this stage.

A much greater incision, here into solid rock below a height of 700 ft., with a relatively shallow gradient and wider valley-floor above, suggests correlation with the Ty-Mawr Stage. A rather long extrapolation to a height of 462 ft. at the present junction does nothing to disprove this correlation.

The most remarkable knick-point found on the tributaries occurs below 520 ft. on the Llanfihangel. The river plunges down into a narrow V-shaped wooded gorge incised into the old valley-floor. A marshy, flat valley-floor above 520 ft. suddenly gives way to this picturesque incision. Extrapolation of the valley-floor above 520 ft. to the junction with the Ystwyth at 390 ft., links it with the Cwm Ystwyth Stage.

Irregularities make the interpretation of the rest of the profile a difficult task. From field experience it is suggested that the larger breaks at 370 ft. (Hafod Stage) and 269 ft. (Llolwyn Stage) are significant. Again, the incision below and the open-valley form above are characteristic. The other breaks discernible on the plotted profile have no particular geomorphological expression on the ground.

Summarising for the Afon Llanfihangel, the knick-points are found at the following heights and are associated with the following stages:

(a) 268 ft.	Llolwyn Stage
(b) 370 ft.	Hafod Stage
(c) 520 ft.	Cwm Ystwyth Stage
(d) 700 ft.	Ty-Mawr Stage
(e) 830 ft.	Coastal Plateau

(f) **Afon Mawr.**—The profile shows four breaks at heights of 270, 330, 430 and 525 ft. Extrapolations to the present junctions give links with the Crosswood, Llolwyn, Hafod and Cwm Ystwyth Stages at heights of 190, 230, 300 and 400 ft. respectively.

(a) 270 ft.	Crosswood Stage
(b) 330 ft.	Llolwyn Stage
(c) 430 ft.	Hafod Stage
(d) 525 ft.	Cwm Ystwyth Stage

5. SUMMARY OF EVIDENCE

Crosswood Stage (approximately 100 ft. base-level).—A knick-point at 170 ft. on the river and breaks in some tributary-profiles suggest grading to such a stage.

Llolwyn Stage (160–180 ft.).—Valley-benches point strongly to the existence of this stage but there is no evidence of a knick-point on the Ystwyth relating to it. It is possible that the 90 ft. of the Pontrhydygroes knick-point is a composite one.

All the tributary-profiles show attempts at grading to this stage.

Hafod Stage (233 ft.).—Long profile, valley-benches and tributary long profiles all contribute to the mass of evidence for this stage.

FEET

TRIBUTARY PROFILES AND EXTR

600

400

200

TY MAWR STAGE

CWM YSTWYTH STAGE

HAFOD STAGE

LLOLWYN STAGE

CROSSWOOD STAGE

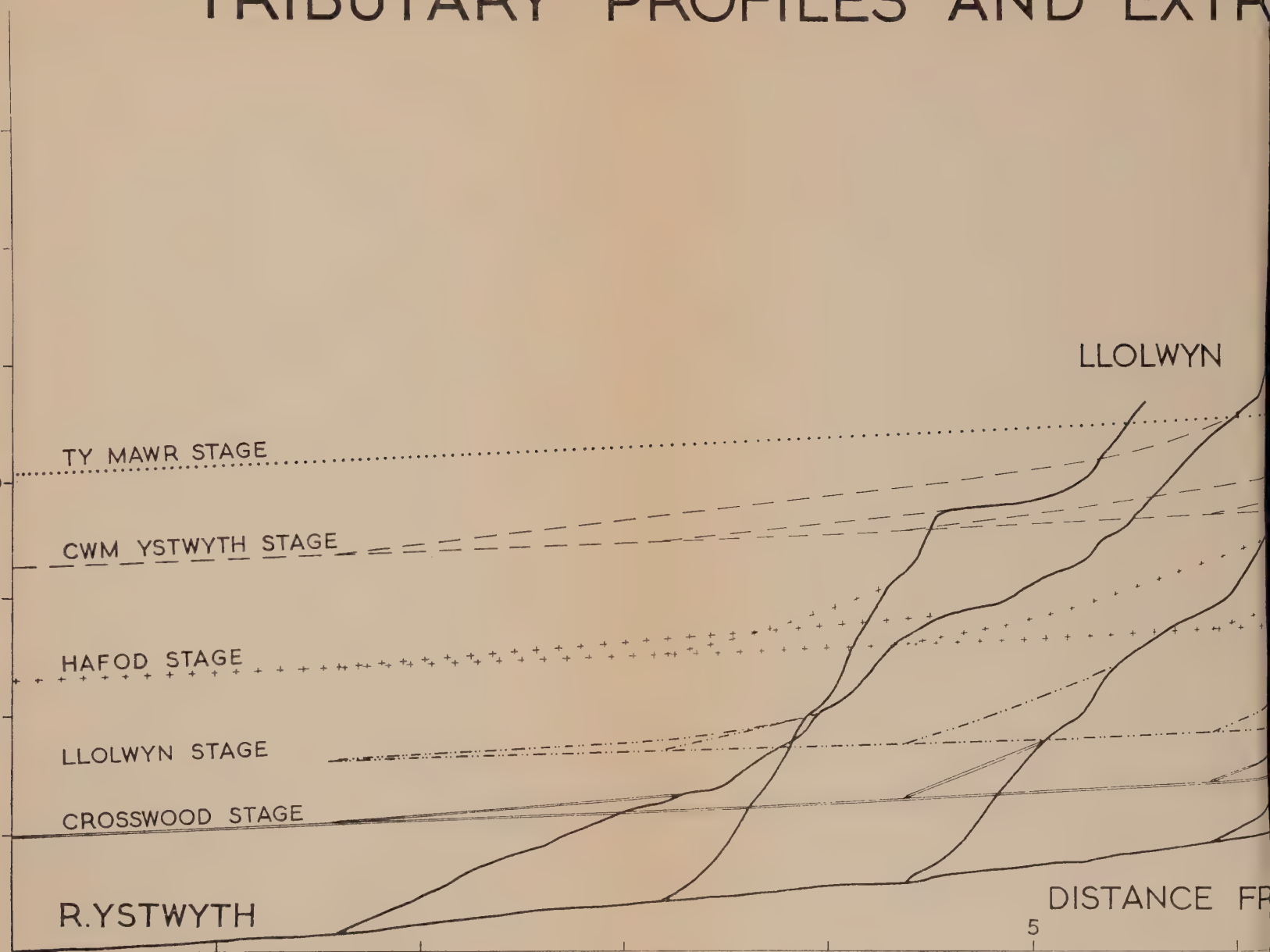
R.YSTWYTH

LLOLWYN

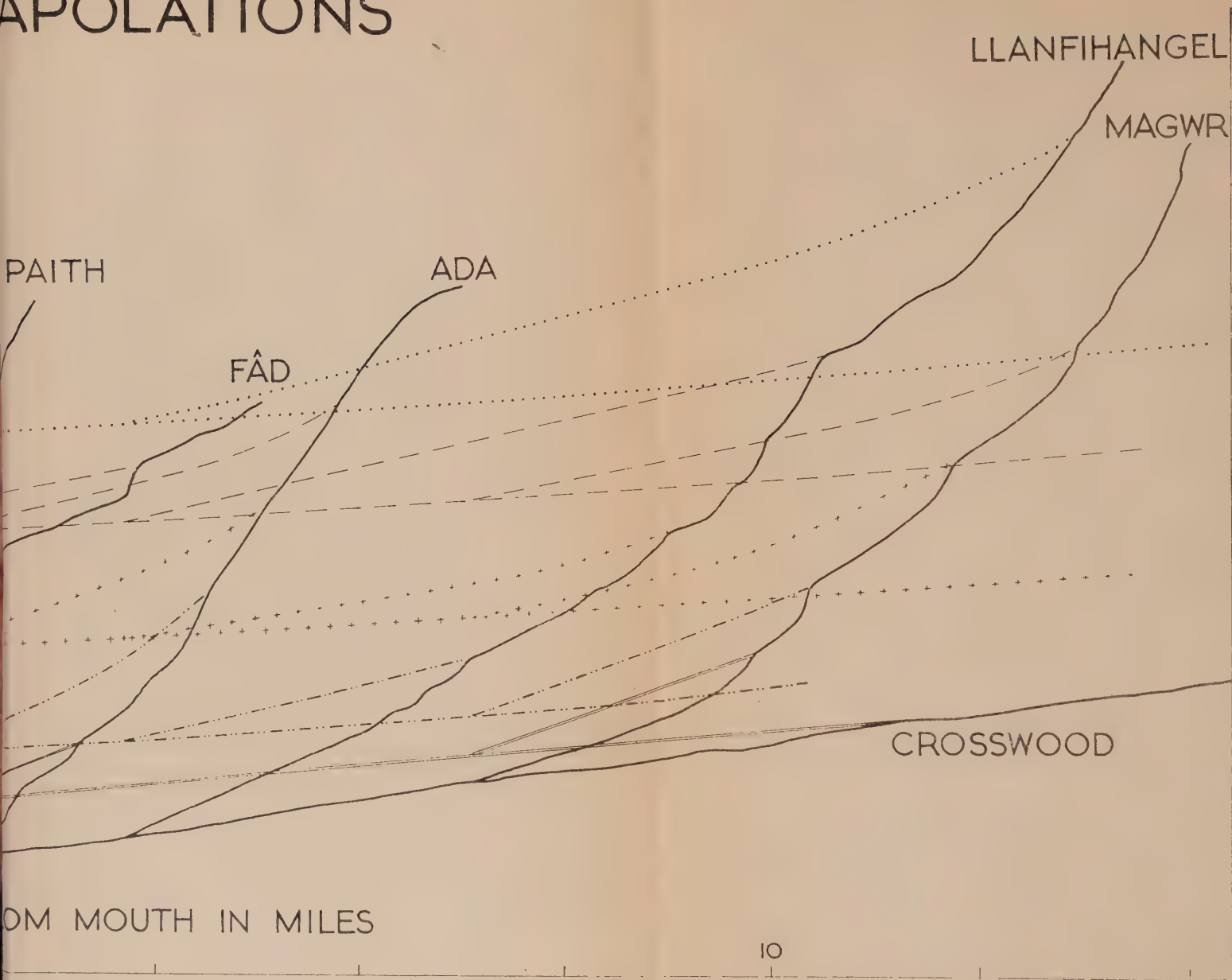
DISTANCE FR

5

Fig. 5.—Tributary-profiles and



APOLATIONS



their extrapolation.

Cwm Ystwyth Stage (327 ft.).—Again all three lines of evidence converge.

Ty-Mawr Stage (407 ft.).—The extrapolated profile and valley-benches are the main lines of evidence together with one tributary-profile—that of the Llanfihangel.

6. ORIGIN, CORRELATION AND AGE

The features dealt with are the direct result of changes in sea-level and consequent rejuvenation. Moreover, the evidence within this small area may be added to the much larger mass building up elsewhere in favour of the eustatic hypothesis. There are no independent dating-media in the Ystwyth Valley but the general fit of the results, with those from other river and platform studies, suggests stability of the land-mass at least since the earliest stage here dealt with, i.e. late Pliocene times.

(a) **Wales.**—In North Wales several platforms have been recognised. Greenly (1919, p. 779) recognises the Menaian platform to which he gives a height of between 200 and 300 ft. in Anglesey. This is over 400 square miles in extent with a gradient westwards of approximately 6.9 ft. per mile and Greenly postulates a further extension westwards. He regarded it as marine in origin and late Tertiary in age. The same platform has been recognised in the area by Dewey (1918, p. 156) and Hollingworth (1938, p. 72). This surface would seem to be the marine-cut platform associated with the sea-level to which the Hafod Stage is graded.

In the same area Dewey recognised the Tregarth shelf at 430 ft. on the fringe of the Snowdon massif. There is also evidence on the monadnocks in Anglesey, which rise above the Menaian platform, of shoulders at approximately 430 ft. Hollingworth again confirms this level. The Tregarth surface is probably identical with the *Ty-Mawr Stage* on the Ystwyth.

In South Wales much more evidence is available and more stages have been recognised. The '200-ft.' Stage, which may be taken as the equivalent of the Hafod Stage, is the most prominent. It is recognised by K. L. Goskar and A. E. Trueman (1934, p. 474), F. J. North (1929, p. 33), R. O. Jones (1939, p. 561) and T. N. George (1938), who all postulate a height of 200–250 ft. for it. It is not recognised by Hollingworth.

T. N. George (1942), in a quantitative approach, places the sea-level of his Talley Stage at 185 ft. approximately. It is difficult to say whether this correlates with the Llolwyn Stage of the Ystwyth or not. Above the Talley Stage on the Towy and Usk there is a gap, until the Fanog Stage, at 430 ft., is reached. It may be that the Talley should be equated with the Hafod Stage.

Above the '200-ft.' platforms of South Wales, all four writers tentatively agree to a surface of marine origin between 300 and 350

ft. It is not very well developed but sufficient evidence is found to suggest a still-stand at this height. Confirmatory evidence is given by the Cwm Ystwyth Stage on the Ystwyth which gives an approximate sea-level of 327 ft. Hollingworth has no doubts about the existence of this stage on the basis of his statistical study.

The most strongly developed of the stages is the '400-ft.' Stage. Its height, as given in the various papers, has a range of 400–450 ft. The Fanog Stage of George gives a sea-level of 430 ft. This is a little high compared with the other, admittedly less accurately determined, estimates. The postulated base-level of 407 ft. for the Ty-Mawr Stage is in line with the general opinion.

Above this stage, a surface is found whose general level is given as 600 ft., by Goskar and Trueman, R. O. Jones, T. N. George, Hollingworth and Miller (1937). T. N. George terms it the Nant Stalwyn Stage with a base-level of 580 ft. It is regarded by all as submarine in origin but Miller postulates a sub-aerial origin. This surface is correlated with the Coastal Plateau Stage in Cardiganshire.

Little evidence is available for correlations of the Llolwyn Stage. The suggestion by Goskar and Trueman of a step in the marine platforms of South Pembrokeshire at 160 ft. (Bosherston Flats) is in accordance with the Ystwyth evidence.

A. A. Miller (1946) has recently investigated the surfaces in the Mawddach estuary which is the nearest in space to the Ystwyth work. He recognises a stage at 200 ft., the Ynys Stage. A further sea-level of 400–450 ft., called the Rhyd Wen Stage, is also found. These two are in agreement with the Hafod and Ty-Mawr Stages of the Ystwyth.

Miller (1938) also made a review of the pre-glacial surfaces around the Irish Sea. He is able to recognise three which are strongly developed throughout the basin at 200, 450 and 800 ft. Again the Hafod Stage, and possibly the Ty-Mawr, are here represented.

(b) England and the Continent.—Over the remainder of the British Isles, surfaces at varying heights above sea level have been found. Correlations along the south coast have been made by J. F. N. Green (1936) and the statistical study by Hollingworth (1938) suggests that similar causes have given rise to remarkably similar results throughout the length of the western seaboard of England.

The '200-ft.' Stage (Hafod) and the '400-ft.' (Ty-Mawr) features are the most widely recognised below the late Pliocene shoreline, which on a height basis can be traced from the London basin, along the south coast, into South-west England and into Wales; thence it may be followed into the Lake District. The Cwm Ystwyth (327-ft.) Stage is less widely recognised but still forms a feature in some regions, e.g. in the Lake District (Hollingworth, S. E., 1938), Brittany (Baulig, H., 1933, p. 43) and the South Downs (Bull, A. J., 1936, p. 125).

In a recent paper, J. F. N. Green (1949, p. 122), in writing of the history of the River Dart, attempts to correlate his results in southern England with probable levels in the Mediterranean (Ball, J., 1939). The table given by Green shows that there is a remarkable coincidence between the stages found in the Mediterranean and those on the River Dart. The correlation is no less vivid, if not as complete, between the Mediterranean and the Dart on the one hand and the River Ystwyth on the other. A table given below illustrates this correlation:

Mediterranean			River Dart		River Ystwyth	
Age	Level		Stage	Level	Stage	Level
	(metres)	(feet)		(feet)		(feet)
Middle Pliocene	180	591	—	595	Coastal Plateau?	
Late Pliocene	154	505	—	505	?	?
	129	423	—	430	Ty-Mawr	407
Early Pleistocene	103	338	Sicilian		Cwmystwyth	327
	72	236	Upper Ambersham		Hafod	233
	57	187	Ambersham		Llwlwyn	160-180
Chellean	41	134	Boyn Hill		Crosswood	100

Recent work by B. W. Sparks (1949, p. 169) has shown a multiplicity of marine benches on the dip-slope of the South Downs between 180 and 475 ft. The lowest, at 180 ft., may be correlated with the Llwlwyn Stage, the 230-ft. may be correlated with the Hafod Stage, the 330-ft. with the Cwm Ystwyth Stage and the Ty-Mawr Stage may possibly be recognised in the 430-ft. marine bench. The remainder of Sparks' levels (290, 345 and 475 ft.) do not appear in the present analysis.

W. G. V. Balchin (*in litt.*), in his study of Exmoor, describes a Georgeham surface, marine in origin, between 300-425 ft. in height, which is possibly related to the Cwm Ystwyth base-level. Similarly his lower Instow surface, 200-280 ft., may be linked with the Hafod level.

So close a correlation between such widely separated areas as the Mediterranean, the South-west of England and Central Wales adds further weight to the evidence in favour of the eustatic hypothesis. The present work shows that it is possible, even in a glaciated region, to analyse land-forms in it and to pick out various stages in its evolution.

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DISCUSSION

PROFESSOR S. W. WOOLDRIDGE said that he wished to pay a tribute to the work which Mr. Brown had been doing in Wales. His paper on the River Ystwyth formed only part of the body of very careful geomorphological work which he had recently undertaken. Two detailed points, perhaps, called for some comment. It was possibly rather dangerous to seem to distinguish between knick-points due respectively to lithological differences and to headward erosion, since in many cases they were, inevitably, one and the same thing. In general it was not possible to explain away a knick-point by correlating it with some hard band. When rejuvenation reached such a band, the knick-point was retarded in its upstream course for some time and at any given moment a number of knick-points would be found so held by a resistant rock-element. The second point concerned the valley-side flats. It should not be a matter for surprise if some of these fell, as it were, out of sequence. As Professor Baulig had frequently insisted, a polycyclic valley might show a surviving flat at any level between its present floor and the highest series of flats recorded, since the river had evidently occupied all levels in succession between the highest and lowest points of the series.

It was natural that authors working in this field should discuss the correlation of their work with that in other regions. In broad terms there was no doubt

whatever that the stages recorded by Mr. Brown had analogues in many other British areas. What was chiefly wanted now, however, was a multiplication of careful studies such as that of Mr. Brown, leaving the problems of wider correlation to be settled when the evidence was fully to hand.

PROFESSOR A. A. MILLER remarked on the value of careful instrumental surveys in providing fuller and more precise information about the shape of the land than could be obtained from maps. He stressed the danger of basing, too confidently, the reconstruction of stages in geomorphological evolution, on what is in reality nothing more than a series of working hypotheses, by no means verified. Among the many unproved assumptions is the one that graded reaches exist and that each one has a gradient diminishing downstream in the form of a logarithmic curve. The diagrams showed that the Dologau Terrace falls some way below the extrapolated curve at a distance of about three miles from its mouth, and the Pont Rhyd-y-Groes Terrace has a parallel downsag at about four and a half miles from the mouth. May not this parallel and persistent downsag display a form characteristic of and proper to the Ystwyth, the departure from the smooth curve being due to some such disturbing factor as the entry of a tributary?

A second assumption is that the five levels described are the only base-levels to which the valley-side terraces were graded, i.e. that base-level fell virtually instantaneously to the next lower level. May not some of the terrace fragments at inconvenient heights have been produced by partial grading to intermediate heights during a period of changing base-level?

A third, and quite erroneous, assumption is that the river mouth was always where it now is, and that former thalwegs should be extrapolated to that point. Beyond the present coastline, cliffed at 500 ft., the encroachment of the sea has destroyed a considerable width of former coastal plateau over which the Ystwyth must have flowed as a further extended consequent after each successive sea-level fall had laid it bare; and since the gradient of the river, even in its lower course, is not inconsiderable, the altitude of the confluence with the sea must depend on its position.

MR. E. H. BROWN, in reply, thanked Professors Wooldridge and Miller for their remarks. He would agree that the scatter of valley-benches between the major gaps on the valley-bench diagram is indicative of continuous rejuvenation. But the very existence of the gaps shows that there have been times of more rapid changes in base-level, following which most of the incision had occurred.

Extrapolations were made to the existing coastline, which of course was not necessarily the coastline at the five stages, and, therefore, the base-level of erosion of those times. However, the gradients of the extrapolated curves at the present coast are less than the gradient of the present river at this point. This strongly suggests that the coastline at the five earlier stages was not far seaward of the present one. This reasoning has been amply confirmed by Professor Alan Wood, who, since this work was completed, has discovered on the present cliff-face, near Aberystwyth, evidence of marine-cut benches equivalent to the Crosswood, Hafod and Cwm Ystwyth Stages (*Geol. Assoc. Circular*, No. 542, 1951-2).

SWANSCOMBE MAN

By Kenneth P. Oakley, Ph.D., F.G.S., F.R.A.I.

(Third Henry Stopes Memorial Lecture, delivered 4 July 1952)

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SUMMARY.—Stone hand-axes of Acheulian type have been found in Pleistocene deposits at numerous localities in Western Europe, Africa and south-western Asia, and were evidently made for scores of thousands of years. Only one undoubted braincase of an Acheulian hand-axe maker is known: that comprised by the occipital and parietal bones discovered by Mr. A. T. Marston in June 1935 and March 1936 in the Middle Gravels of the 100-ft. Terrace of the Thames, in the Barnfield pit at Swanscombe, Kent. Professor W. E. Le Gros Clark and Dr. G. M. Morant have reported that *in so far as it is preserved* this skull shows no feature which distinguishes it from skulls of *Homo sapiens*. However, it has some primitive traits, and the question of its relationship to Neanderthal Man on the one hand and to modern man on the other is still open to discussion. Comparison has been made with the Piltdown and Fontéchevade braincases.

The first important discovery of Palaeolithic implements in association with remains of extinct animals in the 100-ft. Terrace at Swanscombe was reported by Henry Stopes in 1900. The stratigraphy, palaeontology and archaeology of the Swanscombe high-terrace deposits became known in considerable detail as a result of the subsequent investigations of Messrs. Henry Dewey, Reginald A. Smith, R. H. Chandler, M. A. C. Hinton, A. S. Kennard and A. T. Marston. It is now possible to sketch the ecology, to determine the precise geological age, and to discuss in general terms the culture of Swanscombe Man.

In reviewing the Swanscombe dating evidence, the opportunity is taken to consider the claims to antiquity of various human remains found in Pleistocene deposits containing flint hand-axes. The Swanscombe skull alone among these stands up to the fluorine test of contemporaneity with associated fossils. It is now referred to the closing stage of the Second or Great Interglacial period (indicating an antiquity of at least 100,000 years).

1. HISTORICAL PERSPECTIVE

THE discovery of the Swanscombe Skull in 1935 may be regarded as the culminating point of a remarkable story of scientific enquiry which began with the finding of the first flint hand-axe in Gray's Inn Lane, London, about 1690. A London pharmacist, named

Conyers, recovered this pointed flint implement (Fig. 1) from gravel, which also contained the remains of an elephant, and a quarter of a century later an account of it was published by John Bagford¹ who described it as 'a British weapon like unto the head of a spear'. Some eighteenth century antiquarians considered that it had been used by a

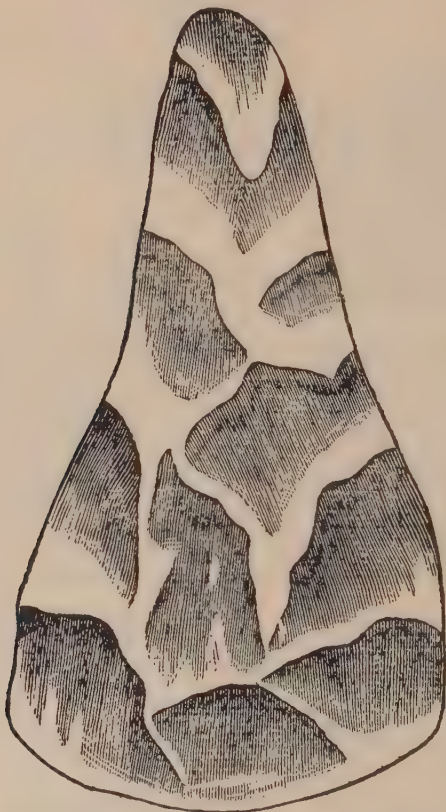


FIG. 1.—Acheulian hand-axe from Gray's Inn Lane, London, c. 1690. Drawing in Hearne's edition of Leland, *De Rebus Britannicus Collectanea*, 1, Oxford, 1715. Two-thirds natural size.

Briton in attacking one of the elephants which accompanied the army of the Emperor Claudius. Flint implements of the same type were next found in 1797 in a drift deposit at Hoxne, Suffolk, where they were recognised by John Frere as 'belonging to a very ancient period

¹ In Hearne's edition of Leland, *De Rebus Britannicus Collectanea*, 1, Iviii, Oxford, 1715.

indeed', and as having been 'used by a people who had not the use of metals'.

Frere's brilliant deduction was ignored by his contemporaries. Indeed, the idea that man had existed in the diluvial period (or as we would now say, in the Pleistocene Ice Age) was a scientific heresy during the first half of the last century. When, in 1846, a French customs official and excise officer, Boucher de Perthes, announced that he had discovered in the ancient gravels of the Somme, at Abbeville, flints worked by man and associated with remains of extinct animals, the majority of archaeologists and geologists were frankly scornful of his claim. In 1854, one of the critics, a physician, Dr. Rigollot, was converted by finding similar flints in fossiliferous river-gravel at St. Acheul, a suburb of Amiens. In the autumn of 1858, the English palaeontologist Hugh Falconer visited Abbeville and, on seeing the evidence, was favourably impressed. In the following April, at Falconer's suggestion, Prestwich went to Abbeville and St. Acheul, and, after examining the collections and visiting the pits in company with John Evans, the archaeologist, he returned to London and read a paper to the Royal Society announcing his acceptance of the claims made by Boucher de Perthes and Rigollot. This announcement, coming from a geologist of such high repute, had a great effect on scientific opinion. The year 1859 was, in fact, one of the turning points of human thought: the high antiquity of man was established, almost simultaneously with the publication of Darwin's *The Origin of Species*. In succeeding years, early stone implements like those of Gray's Inn Lane, Hoxne, Abbeville and St. Acheul, were discovered at numerous localities in the river-valleys of England and France; in 1863 they turned up in Spain, in the same year in India (Madras), and, in 1873, in South Africa (Victoria West). The pioneer whom we honour tonight, Henry Stopes, was the first to find a palaeolithic hand-axe in Egypt. That was in 1880. It so happened that, about this time, the first flint hand-axes were being found in the ancient Thames gravels at Swanscombe in North Kent.

According to the late Mr. A. S. Kennard there was a local tradition that Harry Lewis, a shoemaker from Camberwell, was the first to find hand-axes in the Swanscombe gravels. When Henry Stopes heard of these finds in 1887, he at once visited the locality. In 1892 he went to live there, and spent most of his spare time in the remaining years of his life amassing an unequalled collection of hand-axes and other flint artifacts from the Swanscombe gravels.

We now know that, for at least 100,000 years, the bifacial 'hand-axe' was one of the principal articles of equipment of early palaeolithic hunters throughout Africa, south-west Asia and Europe west of the Rhine. In Europe, the earliest types, called Abbevillian or Chellean, coarsely flaked as if by means of a hammerstone, occur in deposits laid down early in the Second Interglacial period (some authorities



FIG. 2.—Distribution of Chelleo-Acheulian hand-axes. *Based on H. L. Movius.*

claim that Chellean hand-axes occur in First Interglacial deposits). The succeeding types, called Acheulian, more refined in workmanship and largely made by using a bone or wooden striker, are found in deposits ranging in date from the Second Interglacial to the First Interstadial of the Würm Glaciation. Chelleo-Acheulian hand-axes

have been found in Pleistocene deposits at countless localities in the area of their distribution, which amounts to nearly a quarter of the land-area of the world (Fig. 2). But what of the men who made these hand-axes? Were they of one race? Were they of one culture? What was their ecology?

2. PROBLEMS OF FINDING AND DATING HAND-AXE MEN

In view of the vast quantities of Chelleo-Acheulian hand-axes which have been found, their long time-range and their wide distribution, it is astonishing that the incomplete braincase from Swanscombe, a small scrap of jaw found at Makapan in South Africa, a worn molar tooth and the shaft of a femur from one of the Mount Carmel caves, are the only undoubted skeletal remains of the hand-axe makers. In striking contrast, we have remains of more than fifty individuals of the Neanderthal 'race' which, in Western Europe and south-west Asia, supplanted the hand-axe people.¹ There are probably several reasons for this difference. Neanderthalers commonly lived in caves, practised head-hunting or cannibalism, and, sometimes at least, buried their dead. The hand-axe people mainly lived in open country, rarely frequented caves and, perhaps, neither buried their dead nor practised head-hunting.

Unless their remains were artificially buried or deliberately collected together in a cave or at a living site, the chances of early men being found as fossils are remarkably small. Lord Avebury estimated that, among American Indians living entirely by the chase, the ratio of the number of men to the number of animals on which they subsisted was about 1 : 750. Assuming that, on an average, Palaeolithic men lived four times longer than any of the mammals they hunted, and that all their bones and those of the animals stood an equal chance of preservation, one might expect to find, on the basis of these figures, that at a given site one bone in 3000 was human. The actual chances of a bone of a Palaeolithic hunter being found fossilised in a river gravel are probably even smaller than these figures suggest. Primates are peculiarly skilled at avoiding the kind of accident that leads to fossilisation. Professor G. H. R. von Koenigswald has pointed out to me that, in the course of one year, the Selenka Expedition discovered in the Trinil Beds of Java 500 specimens of *Axis* deer and only one specimen of fossil monkey (*Macaca*). Granting that some of the cervid specimens would have been shed antlers, this might suggest that the ratio of monkeys to deer in the Java fauna was of the order of 1 : 300. Yet the actual ratio in Java woodlands is now about 1 : 2, or even 1 : 1, and there is no reason to suppose that it would have been very different during the Pleistocene.

¹ Hand-axes of distinctive types, mostly small, were made by some groups of Neanderthalers, but their industries, called Mousterian, consisted *principally* of uniface flake-tools. Thus, in speaking of 'the hand-axe people', the qualification 'pre-Mousterian' is generally implied—or at any rate 'non-Mousterian'.

In late Pleistocene times the brutish-looking Neanderthalers, with their Mousterian culture of supposed Eastern European or Asiatic origin, were suddenly replaced by *Homo sapiens* of several distinct racial types (Cro-Magnon and others). Attempts to explain this fact gave rise to the theory that 'modern man' (*Homo sapiens*) had really been in existence in the African-West European hand-axe province since early Pleistocene times but that his remains were rarely preserved until he adopted the practice of ceremonial burial. Various discoveries have at one time or another been cited in support of this theory of the early origin of *Homo sapiens*, including the Swanscombe skull itself.

The theory was difficult to prove because, when a human skull or skeleton barely different from the modern type is found in a very ancient deposit, the suspicion always arises that it may be a later burial. When a beetle-browed skull of Pithecanthropine or Neanderthal type is found, there is no reason for doubting its antiquity; but naturally it is quite otherwise when the skull in question is indistinguishable from *Homo sapiens*, even if it appears fossilised. During his excavations at Gibraltar in the last century, Captain F. Brome had an experience which is relevant to this last point:

In the excavation of the east fissure the entire skeleton of a horse was met with, at a few feet only below the surface. In general condition the bones presented very much the same character as many of the fossil bones from a greater depth, and had been deprived of the greater part of the animal matter. At first Captain Brome thought he had come upon the remains of a fossil horse; but, to his surprise, when the foot-bones were exhumed, the shoes with which the animal had been shod were found *in situ*; and it was ascertained that the bones, much altered as they were, had belonged to a favourite Arab charger, which had been buried at the spot about twenty-five years before. The instance is a very striking one, in showing the fallacious nature of evidence derived merely from the mineral condition of buried bones when exposed to free percolation of water in a calcareous bed. (Busk in *Trans. Zool. Soc. Lond.*, 10, 1879, p. 90.)

Fortunately the progressive fixation of fluorine by buried bones sometimes provides a useful means of checking whether they are contemporary with the associated fossils or whether they have been buried in at a later date. From time to time during the past century skulls and skeletons, morphologically indistinguishable from modern man, have been found in deposits containing hand-axes, both in Africa and Europe. Many of these have now been tested by the fluorine-dating method, but for one reason or another the theory that hand-axes were made by early *Homo sapiens* is still unconfirmed.

Human remains of modern type, found in European deposits containing hand-axes, include the Moulin Quignon or Abbeville jaw (1863), the Bury St. Edmunds skull (1882), the Galley Hill skeleton (1888) and the Dartford skull (1902); and one might, perhaps, add the Baker's Hole skull found about 1902 in deposits containing Acheulo-Levalloisian tools. After Professor Le Gros Clark and Dr.

Morant reported that, in so far as it was preserved, the Swanscombe skull showed no feature which would exclude it from *Homo sapiens*, there was a revival of interest in these old finds which had been discarded largely on account of their modern morphology and the consequent doubt as to their antiquity. The fluorine content of all these doubtful specimens has now been measured (Table I) and in each case proved to be so low in comparison with that of fossil animal bones undoubtedly contemporary with the hand-axes, that there can be little doubt that they are intrusive burials, end-Pleistocene or early Holocene in age.

Table I.—FLUORINE-DATING OF HUMAN REMAINS FOUND IN DEPOSITS CONTAINING FLINT HAND-AXES

Specimen	% Fluorine	Minimum recorded % F in local fossils contemporary with deposit	Maximum recorded % F in local Holocene bones
Moulin Quignon jaw	0.2	0.9	0.1
Bury St. Edmunds skull	0.2	1.6	0.2
Galley Hill skeleton	0.4	1.5	0.3
Dartford skull	0.1	0.9	0.3
Baker's Hole skull	0.3	0.9	0.3
Swanscombe skull	2.0	1.5	0.3

Those who are familiar with the conditions under which the Swanscombe skull was found, could not question that it is a fossil contemporary with the Acheulian hand-axes which lay in the same bed; but as doubts on this score have been expressed from time to time, it is extremely satisfactory to be able to set on record the fact that the 'fluorine test' has provided complete confirmation of its Acheulian age.

Whether or not the Swanscombe skull does in fact represent *Homo sapiens* is still uncertain, but it is well to remember that, at Kanam in Kenya, Dr. L. S. B. Leakey found a highly mineralised human mandible of modern type in association with Pre-Chellean pebble-tools; and, at the nearby locality of Kanjera, cranial fragments of modern type in proximity to Acheulian hand-axes. These may well be contemporary with the deposits in which they occurred, but since Professor P. G. H. Boswell published his view that the evidence for their antiquity was doubtful, they have had to be placed in a suspense account.¹ The fluorine-dating method unfortunately proved inapplic-

¹ See correspondence in *Nature*, London, 135, 371, 9 March 1935; *ibid.* 138, 643, 10 October 1936.

able to the Kanam and Kanjera specimens, owing to the random and unusually intense character of the mineralisation which has occurred in these beds as a result of the volcanic environment and semi-arid tropical-weathering conditions.

3. DISCOVERY OF THE SWANSCOMBE SKULL

The story of the discovery of the Swanscombe Skull by our member, Mr. Alvan T. Marston, is a remarkable one. Mr. Marston, like his predecessor, Henry Stopes, began to pay regular visits to the Swanscombe gravel pits in search of flint implements. When he applied to the manager of the company working the pit for a permit in November 1933, he stated as his purpose 'the study of anthropology'. (One is reminded that when Henry Stopes gave a public lecture in the Galley Hill Schools on 10 February 1896, he took as his subject 'Early Natives of Swanscombe'. Like Marston he was primarily interested in the flint implements from the local gravels because they led to a knowledge of the men who made them.)

During one of his visits to the Barnfield pit, on Saturday, 29 June 1935, Mr. Marston noticed a small piece of bone exposed in the working face of the Middle Gravels, about 24 ft. below the ground

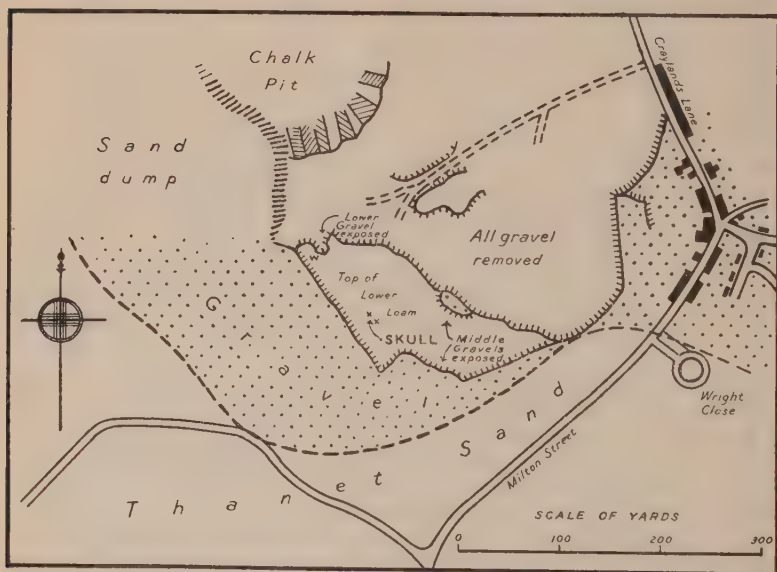


FIG. 3.—Sketch-map of the Barnfield Pit, Swanscombe, showing the position of the skull-site and of the working faces when the pit became disused. Based on Dines, 1938, revised with assistance of Miss J. Andrews, September, 1952.

Note.—It is proposed to preserve a complete witness section at W.

surface. On cleaning it with his fingers, he found that it was a perfect human occipital bone. He removed it for fear that it might be disturbed or broken by collapse of the gravel face if he left it *in situ* (for he was alone in the pit); and, later, obtained a photograph of the hollow matrix which was left in the face. I well remember the excitement which was caused at the Geological Survey on the Monday morning when Mr. Henry Dewey received a letter from Mr. Marston announcing the discovery. Together with Sir John Flett, he immediately visited the pit and they were both satisfied with the authenticity of the find. Mr. Dewey collected the specimen from Mr. Marston's house at Clapham and conveyed it to the Geological Survey Museum, where for some days it was kept under an aura of secrecy. I was a very junior member of the staff at that time, and I see that I recorded in my diary on 3 July: 'Duke of York opened the new Museum. Frisby showed me the Swanscombe skull on the quiet; undoubtedly Pleistocene; very thick-walled; left-handed.' (The latter remark reflects the influence of my former professor, Sir Grafton Elliot Smith, who taught that asymmetry of the type seen in this bone was an indication of left-handedness. Later work by Professor Le Gros Clark showed this correlation to be unreliable).

As the gravel face was worked back, a constant look-out for further human remains was kept, and the particular ferruginous seam in which the bone had been found was carefully followed by Mr. Marston himself. It was not until nine months later that an intensive and almost continuous search was rewarded. On 15 March 1936, he found a human left parietal bone which proved to articulate perfectly with the occipital. Both bones were in the same seam of gravel and at the same depth from the surface, but the parietal bone was 8 yds. away, apparently in the downstream direction (Fig. 3). Although the search was continued beyond that date until the end of 1945, when the seam was completely worked out, no further fragments came to light.

The great importance of the discovery lies in the fact that the gravel in which the fragments occurred also yielded unworn flint hand-axes of Acheulian type (Figs. 5, 7), together with bones and teeth of mammals representing an interglacial fauna.

Mr. Marston undertook a preliminary investigation of the skull and delivered a lecture on his conclusions before the Royal Anthropological Institute in January, 1937. Subsequently he prepared a full report in which he recounted the circumstances of the discovery and stated his own views on the skull and on the geology and archaeology of the site. This report was published in the *Journal of the Royal Anthropological Institute* for 1937. In view of the uniqueness of the discovery, Mr. Marston was anxious that trained geologists and archaeologists should carry out an independent investigation of the data that he had collected. Largely at his suggestion, the Royal Anthropological Institute appointed a Committee to co-operate in

the further exploration of the site and to prepare a series of reports on various aspects of the skull and associated finds. Their joint report on the Swanscombe Skull was published in 1938.

4. GEOLOGY AND ARCHAEOLOGY OF SWANSCOMBE SKULL SITE

The main working-face of the Barnfield pit at Swanscombe, which overlooks the River Thames to the north, formerly had a total height of 40 ft. and exposes a series of gravels, sands and loams. The stratification is remarkably uniform and the following five local subdivisions can be recognised:

5. Upper Gravel and Clay
4. Upper Loam
3. Middle Gravels and Sands
2. Lower Loam
1. Lower Gravel

With the exception of the Upper Gravel and Clay (formed largely by solifluxion) the gravels and associated sands and loams are fluviatile deposits constituting part of the so-called 100-ft. or Boyn Hill Terrace of the Thames. They contain numerous flint artifacts and remains of an interglacial fauna (see p. 289). The first important association of mammalian bones and molluscan shells with Palaeolithic implements in these 'High Terrace' gravels was reported in 1900 by Henry Stopes in the neighbouring pit of Ingress Vale, 450 yds. to the north-west. The stratification and sequence of Palaeolithic industries in the Barnfield pit (in part also known as Craylands Lane, Milton Street and Colyer's pit) was investigated by Reginald A. Smith and Henry Dewey, in a series of classic excavations, during the years 1912 and 1913.

At the time when these gravels and sands were being laid down in the period following the Second or Mindel Glaciation, the Thames meandered over a flood-plain more than a mile wide. The river was continually carving out new channels and then filling them with coarse alluvium, or abandoning them so that they were occupied by slack water or reedy swamps in which loams accumulated. In consequence of this process, no sequence persists very far, for the deposits filling one channel are slightly different in age and character from those occurring at the same level in another channel. These conditions are well illustrated at Swanscombe (Fig. 4). The deposits exposed in the Barnfield pit lie in a broad channel cut in the solid rocks (Thanet Sand and Chalk), with its base at 75 ft. above sea-level and extending from west to east. Mr. Marston showed that there was an important line of erosion in the Middle Gravels representing a period of channelling. The Upper Middle Gravel locally descends into a narrow channel which has been cut through the Lower Middle Gravel and, in its deepest part, through the Lower Loam and Lower

Gravel. The Upper Middle Gravel comprises reddish yellow gravels below, in oblique layers parallel to the bank; and pale yellow cross-bedded sands above. The skull-fragments were found at 94 ft. above sea-level in the oblique seam at the base of the Upper Middle Gravel, as though they had lain on the surface of the scoured-out channel of the river-bed.

Flint artifacts are profuse both in the Lower Gravel and in the Middle Gravels of the Barnfield pit. Those in the Lower Gravel are exclusively flakes and chopper-like cores of the Clactonian industry, here studied in detail by Mr. R. H. Chandler. Clactonian artifacts are also found at the base of the Middle Gravels, and, judging by their patinated condition at that horizon, it seems that they were made at a time when the Lower Loam formed a land-surface. Perhaps the river was then cutting and filling a channel at a lower level. (Indeed, it is probable that the river-channel deposits exposed on the foreshore at Clacton-on-Sea and containing the type Clactonian industry, were laid down by the Thames at this time.)

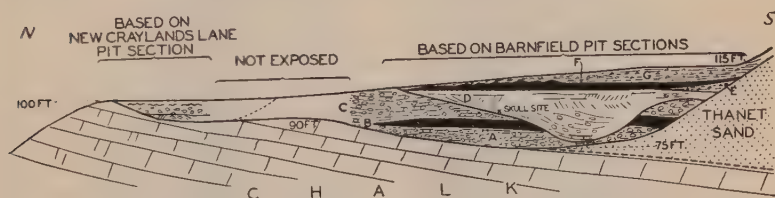


FIG. 4.—Diagrammatic section across the 100-ft. Terrace at Swanscombe, showing the main deposits in the Barnfield Pit. A=Lower Gravel, B=Lower Loam, C=Lower Middle Gravel, D=Upper Middle Gravel (and Sand), E=Solifluxion wedge, F=Upper Loam, G=Upper Gravel (and clay). *Not to scale, but figures indicate heights above Ordnance Datum at key points.* (Based on Dines, 1938).

Human culture is abundantly represented in the Middle Gravels by an Acheulian hand-axe industry. The flint hand-axes (e.g. Figs. 5, 7), which have been recovered from the gravels of this pit since work began there about seventy years ago, amount to tens of thousands. Unfortunately early collectors were inclined to keep hand-axes and to ignore the waste-flakes and misshapen tools. Indeed, the gravel diggers as a rule only kept 'spearheads' (as hand-axes are still called in this district) because they alone fetched a good price. The result is that students now studying the older collections sometimes get the impression that Acheulian industries consist exclusively of hand-axes. In fact that is far from being true. Henry Stopes was a pioneer collector in this respect. When he visited the Swanscombe pits (sometimes in company with Mr. W. H. Dalton of the Geological Survey, often, too, with his daughter Dr. Marie Stopes) he kept every piece of flint that had the slightest, even doubtful signs of work or use, only

discarding them as worthless after prolonged examination and handling and comparison with others of like form. Unfortunately he did not live long enough to publish more than a fraction of his gleanings, and his vast collection, comprising some 80,000 picked implements, the majority from Pleistocene deposits of the Swanscombe-Erith region, still awaits study in the National Museum of Wales.

The richness of these gravels may be gauged by the fact that, in clearing an area of the skull-layer in the Barnfield pit, Mr. Marston and his son recovered in a single day, in July 1935, three hand-axes, four core-like pieces and 34 flakes. In the course of the next year they recovered from this thin seam alone about a dozen hand-axes and 550 flakes and core-remnants. Only about three per cent of the flakes showed secondary trimming as knives or scrapers.



FIG. 5.—Acheulian flint hand-axe from Middle Gravels, Barnfield Pit, Swanscombe. Two-thirds natural size.

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5. CULTURE OF SWANSCOMBE MAN

Until recently most students of the Lower Palaeolithic were inclined to equate tool-type with culture and to say that, in gravels where certain forms of bifacial hand-axe represented the culture of Acheulian man, flakes of Clactonian or Levalloisian types from the same deposit were necessarily made by men of different cultures, or even of different species. Careful excavation of actual *ateliers* or workshop sites of Lower Palaeolithic age has shown, however, that simple rule-of-thumb correlation of this sort is not justified. Of course it cannot be denied that some assemblages of artifacts, such as those in the Swanscombe Lower Gravel and in the Clacton Elephant Bed, represent a culture (the true Clactonian) entirely distinct from the

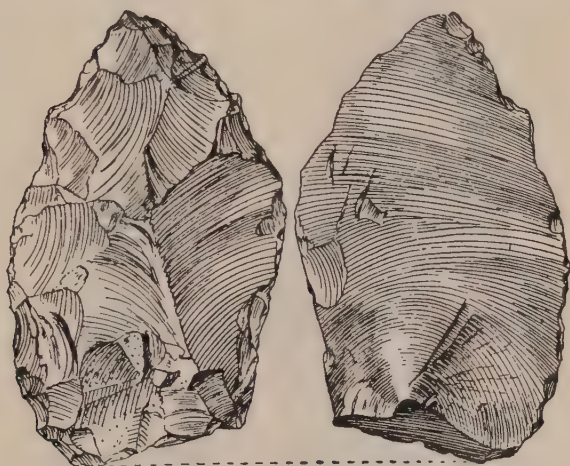


FIG. 6.—Clactonoid flake-tool associated with Acheulian hand-axes in Middle Gravels, Barnfield Pit, Swanscombe. Two-thirds natural size.

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Acheulian *biface* or hand-axe culture which locally succeeded it. But there is also no doubt that Acheulian hand-axe industries include a number of primary waste-flakes of Clactonian form, and also a variable percentage of retouched flake-tools which, isolated from their context, would be regarded as 'advanced Clactonian' (Fig. 6). At some sites industries occur which suggest a blending of the two traditions (e.g. the Acheulo-Clactonian industry at High Lodge in Suffolk).

Some groups of Acheulian hand-axe makers adopted the so-called Levalloisian technique of striking flakes from prepared cores. At one time this was regarded as a practice confined to the 'Mousterian' group of cultures. But flake-blades and cores of Levalloisian type

have recently been found on a Middle Acheulian workshop site in the 30-m. Terrace of the Somme at Cagny. Similarly, flakes, flake-blades and cores of Levalloisian type occur in small numbers in the Middle Gravels at Swanscombe, and they may well have been part of the repertoire of Swanscombe Man.

On the evidence obtained at Lehringen (see below, p. 287), and at a later mammoth-butcherer site at Tomsk in Siberia, we may conclude that many untrimmed flakes were used as tools by Palaeolithic hunters. Stopes claimed that he could recognise signs of use on



FIG. 7.—Acheulian hand-axe made from flint nodule. Middle Gravels, Barnfield Pit, Swanscombe. Two-thirds natural size.

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some of the untrimmed flakes found in the Swanscombe gravels. This is usually very difficult when the flakes are in river gravel. The commonest uses of flakes would have been as knives and scrapers, but Stopes found one flake-blade in the Barnfield gravels which appeared to have been deliberately serrated for use as a saw.

The division of the earlier Palaeolithic industries into those of core-tool tradition and those of flake-tool tradition is becoming blurred through the progress of our knowledge; but there remains, nevertheless, an element of truth in this distinction. Bifacial hand-axes are

essentially core-tools. A number of those found in the Barnfield Middle Gravels have been fashioned from flakes instead of from nodules, but in this case the traditional *idea* has still been preserved, for a flake which is trimmed bifacially into the form of a hand-axe is being treated *as a core*.

The hand-axes associated with the Swanscombe skull (cf. Fig. 5) can be closely matched in the Somme valley assemblages classed by the Abbé Breuil as Acheul III. However, it is doubtful if the seven stages of Acheulian recognised in the Somme are precisely applicable to the sequences found in other parts of north-west Europe, so for the present it is perhaps wiser to describe the industry of Swanscombe Man as Middle Acheulian.

Our knowledge of the culture of Swanscombe Man may be supplemented by considering evidence from other sites of comparable age within the Thames valley. The gravels of Furze Platt, near Maidenhead, forming the Lower Boyn Hill Terrace, appear to be precisely equivalent to the Swanscombe Middle Gravels. Thanks to Mr. Llewellyn Treacher and Mr. A. D. Lacaille, we have an extensive knowledge of the artifacts of the gravels of the Lower Boyn Hill Terrace, which include the great hand-axe that is one of the treasures of our British Museum (Natural History) collections. After examining this specimen, one finds it difficult to regard Acheulian Man as merely an animal getting a living. Surely we see him here as an artist enjoying the exercise of his skill as a worker in flint? Many of the Swanscombe hand-axes of normal size are superbly flaked and finished with a perfection which appears to exceed the requirements of bare necessity.

In regard to the general aspects of the culture of Swanscombe Man, one has no reason to doubt that he was typical of the period to which he belonged. In Lower Palaeolithic times all men lived by hunting animals and gathering wild foods, worms, grubs, roots and berries—just as men beyond the margins of civilisation do today in Australia and South Africa. It has been suggested that hand-axes were used for digging up roots and grubs. Some of the plano-convex pick-like forms may have been so used, but Henry Stopes, who examined thousands of hand-axes from the Swanscombe gravels, noticed how many of them had fine undamaged points, and concluded that these were certainly never used for, or intended for, digging.

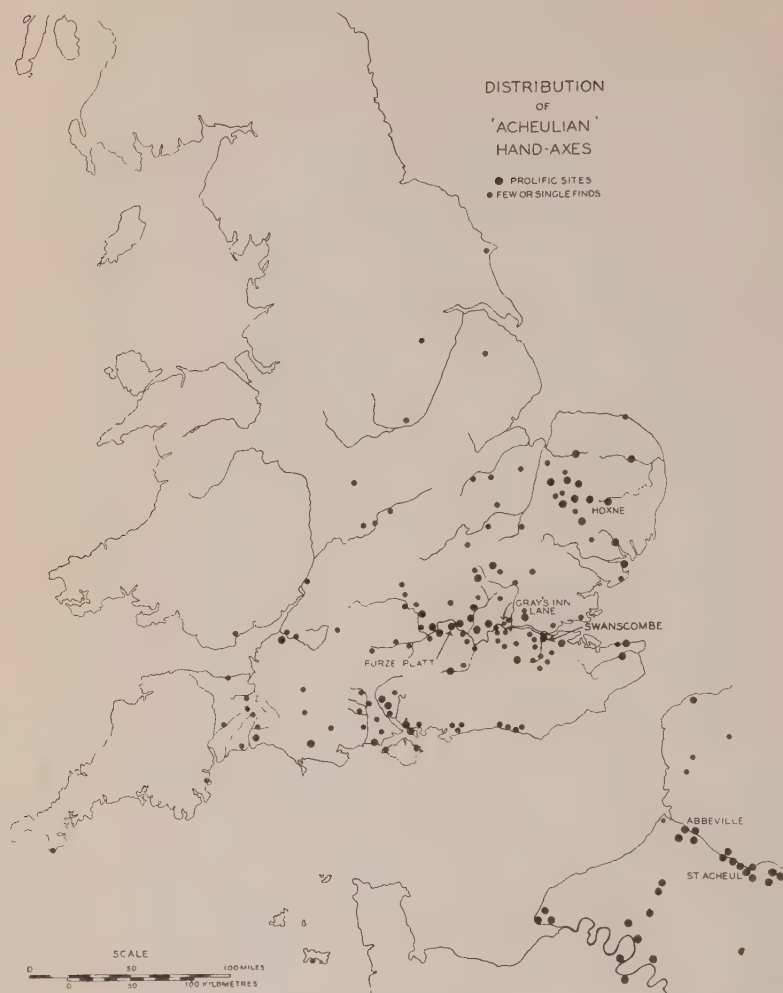
The term hand-axe is unfortunate because, with the possible exception of the straight-topped variety known as the cleaver, they were probably not used as axes in the usual sense. The typical hand-axe (the term is the English equivalent of the more expressive French name, *coup-de-poing*) was evidently a general purpose tool, used mainly for cutting and scraping. Mr. A. J. Arkell has shown by practical demonstration that some types of hand-axe serve excellently for skinning game, and that, no doubt, together with dismembering the animal, was one of their chief uses.

Dr. L. S. B. Leakey found that, at certain levels in the lake beds exposed in the Olduvai Gorge, Tanganyika, there were concentrations of hand-axes very suggestive of butchering-sites at the fluctuating lake-margins. In the midst of one of these concentrations, which included a fair quantity of waste flakes and lumps of raw material, excavation revealed the dismembered skeleton of a hippopotamus. It is, perhaps, not too far-fetched to see in these remains the relics of a communal feast such as occurs from time to time in Africa today. If a hippopotamus is killed and brought to shore, scores of natives collect in the course of a few hours and spend the next day or two cutting up and consuming the carcase. Each man brings his own iron knife and, owing to the toughness of the animal's skin, these are constantly re-sharpened. Instead of re-sharpening their hand-axes, Acheulian hunters may frequently have discarded them, as they became blunted, and made new ones.

It may well be that the majority of the flint implements in the Swanscombe gravels were chipped in similar circumstances. Anyone who has seen M. Léon Coutier fashioning a flint hand-axe will realise that a skilled worker requires less than five minutes to complete one. With ample supplies of flint nodules close at hand in the river-cliffs, there would have been no need for the early natives to take great care of their implements; new hand-axes were probably made whenever there was an important kill. Thus, in spite of the profusion of hand-axes in the gravels here and at other localities in this valley, we need not suppose that the Acheulian people were ever very numerous. At certain points by the river, where animals came to water, or at boggy places into which they could be driven, kills would have been more frequent than elsewhere. We have only to suppose that, on an average, ten tool-making individuals frequented the river-banks at Swanscombe during a week and that each made and discarded there two or three hand-axes, and we would have accounted for more than one million of these tools being possibly incorporated in the river-bed at that locality within thirty generations.

Judging by the habits of primitive peoples living today on a comparable level of subsistence (such as the Australian aborigines and the African Bushmen), we may presume that among the Acheulians the *family-group* would have been the foraging unit, but that a number of these, forming a *band*, would have co-operated in some activities, as in the hunting of large game. In Australia a band varies in size from 30 to 100 individuals, but, according to Professor Julian Steward,¹ the average number is 35. A single band usually operates within a fairly well-defined territory to the exclusion of others. The size of this territory varies from about 150 to 500 sq. mi. or more, depending on the mobility and hunting skill of the band, and on the abundance of game and other foods. In the case of a riverine

¹ *Essays in Anthropology presented to A. L. Kroeber*, 341. California University Press, 1936.



Provisional map of the distribution of Acheulian hand-axes in Britain and North-eastern France.

Note.—All the prolific sites ('stations') and the majority of the isolated or scattered finds plotted on this map are Acheulian in the strict sense. Thus, Mousterian sites yielding hand-axes have been omitted. However, it has not been possible to check all the published records by examination of the specimens, and, therefore, the isolated and scattered finds in Britain may include some hand-axes which are Abbevillian (Chellean), Acheulo-Mousterian or Levalloiso-Acheulian. The positions of the main Acheulian sites in NE. France were for the most part kindly supplied by Mr. Harper Kelley; Miss A. E. Ashworth helped in the preparation of the map.

[To face p. 287.

band the length of the territory considerably exceeds its breadth. In 1833, Charles Sturt encountered only about fifty aborigines (probably a single band) along the whole of the Upper Murrumbidgee River, which is nearly as long as the Thames and situated in an area of dependable rainfall. Within the territory of a band, one might expect to find a marked uniformity of tool-types, and it is possible that, by plotting the areal distribution of hand-axes with local or idiosyncratic traits at a particular horizon in the 100-ft. Terrace of the Thames, we may eventually be able to form a rough estimate of the number of territories into which the valley was divided during, say, Middle Acheulian times.

A provisional distribution map of Acheulian hand-axes in Britain and north-east France (Plate 10) suggests that their makers lived mainly in open country, and that their movement was largely confined to shore-lines and river-valleys. At that time, of course, Britain was joined to the Continent, forming a large peninsula.

The population of the British peninsula during Pleistocene times no doubt fluctuated widely with climatic changes and with the consequent variation in the abundance of game and in the character of the available wild foods. On the basis of the range of population-density in Arctic America, Professor Grahame Clark¹ has estimated that the population of Britain in Upper Palaeolithic times (under a sub-glacial climate) would have been between 250 and 2000, probably nearer 250 in winter months. During interglacial times the situation was different, but it is unlikely that the Lower Palaeolithic population of Britain ever comprised more than about a dozen bands. So long as there was the possibility of free movement between France and Britain, this population would probably not have been genetically isolated.

The hand-axe people were evidently skilled hunters of large and fast-moving game, to judge by the quantities and character of the meat-bones found, for example, on the Acheulian camping-sites at Olorgesailie in Kenya and at Torralba in Spain. We can only guess at some of the methods they employed; but fall-traps, snares and slings are probable. The flint artifacts in the Acheulian gravels at Swanscombe include polygonal lumps which were considered by Stopes to be possibly missiles. The finding at Olorgesailie of deliberately-shaped stone balls, sometimes in groups of three, was regarded by Dr. Leakey as evidence that the African Acheulian hunters used the *bolos*, but this is still regarded as questionable.

All-wood spears were probably the principal weapons of Lower Palaeolithic hunters in Europe. The point of one made in yew-wood was found by Mr. Hazzledine Warren in the water-logged peaty deposit with type Clactonian industry at Clacton-on-Sea. At Lehringen, near Bremen in Germany, a complete yew-wood spear

¹ *Archaeology and Society*, 178. London, 1939.

nearly 8 ft. long and with fire-hardened tip was recently found within a skeleton of *Elephas antiquus* in a lake-bed of Third Inter-glacial age.¹ Scattered among the elephant bones were about two dozen untrimmed flint flakes which had evidently been used by the hunters in skinning the animal. (The Lehringen culture is regarded as probably a Levalloisian facies of Late Acheulian.)

Professor Jacob-Friesen and Dr. J. Janmart have drawn attention to the elephant-hunting methods used by Congo Pygmies as providing possible parallels to those used by the Palaeolithic hunters in Europe.² The Pygmies in the Ituri Forest first smear their bodies in mud and then hide in a pool where the animals have their daily mud-bath; when opportunity offers, the hunter sneaks underneath the standing animal and thrusts his spear upwards into its soft belly with lightning-quick movement. The wounded animal may charge away but then the spear usually penetrates even more deeply into its entrails and hunters can follow it until it dies.

Henry Stopes made one observation in regard to the culture of Swanscombe Man which as far as I know has not been contradicted by later workers. He said that he had never seen any evidence in the Swanscombe gravels that the hand-axe people used fire.³ In his Stopes Memorial Lecture, published in the last volume of our PROCEEDINGS, Mr. Hazzledine Warren made the same observation in regard to the culture of Clactonian man at Clacton. Dr. Leakey found no evidence that fire had been used by the Acheulian people at Olorgesailie. Thus it seems probable that some Lower Palaeolithic groups ate their meat raw, or perhaps dried like *biltong*. On the other hand, evidence of the use of fire has been found at the Early Acheulian camping site at Torralba in Spain (over 3600 ft. above sea-level), and at numerous Late Acheulian, Late Clactonian and Mousterian sites in Europe and Asia.

As regards the perishable aspects of Acheulian culture, it is worth while recalling that, in his description of the Acheulo-Clactonian 'floor' in the Middle Terrace sands at Stoke Newington, Worthington G. Smith⁴ recorded the discovery of two artificially-pointed birch stakes, 4 ft. long, associated with charred wood, branches of *Clematis* and matted fronds of *Osmunda regalis*. He believed that these remains, which were mingled with the flint flakings, represented a Palaeolithic dwelling: a wind-break such as the Tasmanians used.

6. BIOTOPE OF SWANSCOMBE MAN

It was fortunate that the Swanscombe skull was found in deposits which yielded abundant faunal remains, because these enable us to

¹ See H. L. Movius. *Sthwest. Journ. Anthropol.*, Albuquerque, 6 (1950), 139-42.

² *American Anthropologist*, Lancaster, Pa., 54 (1952), 146.

³ Small red flint pebbles occur in the Swanscombe gravels, as they do in most flint drifts, but those which I have seen lack the crackled appearance which is the hall-mark of fire.

⁴ *Man, the Primeval Savage*, 268, London, 1894.

determine its relative age with fair precision, and, at the same time, to deduce the character of the biotope.

The larger Mammalia in the Middle Gravels at Swanscombe have been studied by Mr. M. A. C. Hinton and the late Miss D. M. A. Bate. They include (according to the latest revision): *Elephas antiquus*, *Elephas* cf. *primigenius*, *Rhinoceros mercki* (*megarhinus*), *Cervus elaphus* (large), *Dama clactoniana*, *Megaceros*, *Bison* and *Equus*, which indicate that the Thames was bordered by woodlands interspersed by grassland. This fauna is very similar to that of the preceding Lower Gravel Stage, although horse and bison appear to have become commoner, suggesting an increase in the proportion of grassland.

No direct evidence of the flora has been obtained from the Swanscombe gravels, but we now know the pollen sequence in the Clacton channel deposits¹ which are probably intermediate in age between the Swanscombe Lower Gravel and the Middle Gravels. Before the end of the Clacton Stage, mixed oak-woods had given place to coniferous forests dominated by silver fir (*Abies*). This development was characteristic of the second half of the Great Interglacial. The Middle Gravels, being somewhat younger than the Clacton stage, thus evidently belong to the closing stage of that Interglacial (Table II).

Table II.—STRATIGRAPHICAL POSITION OF SWANSCOMBE SKULL

Lower Thames Swanscombe Sequence		Stages Netherlands	Glaciations (Germany & Alps)
Upper Gravel & Coombe Rock		DRENTHIAN	Saale (Main Riss)
Upper Loam Middle Gravels, with horizon of SWANSCOMBE SKULL			‘SECOND Glütsch ?
Land-surface Lower Loam Lower Gravel	Clacton channel deposits		
Hornchurch Boulder Clay		TAXANDRIAN	Elster (Mindel)

The remains of a number of small mammals were found by Mr. Marston in a silt layer in the Upper Middle Gravels. These include several extinct voles, *Microtus agrestis-arvalis*, *M. ratticepoides* and a species of lemming (*Lemmus*). It is surely significant that lemming makes its first known appearance in the Drenthian Stage of the Dutch Pleistocene sequence where it is accompanied by *M. ratticepoides*? The Clacton Stage can be equated on pollen evidence with the Dutch Needian Stage which precedes the Drenthian; so it seems to follow that the Swanscombe Middle Gravels can be equated with

¹ Pike, K. and H. Godwin. *Quart. Journ. Geol. Soc. Lond.*, forthcoming in 1953.

the earlier part of the Drenthian (or 'Dutch High Terrace'), for this correlation is supported by the evidence of the small mammals.

However, the *Upper* Drenthian corresponds with the maximum of the Saale Glaciation of North Germany and the Netherlands (= Third or Riss II Glaciation in the Alps); so that this correlation raises the question of whether the Swanscombe Middle Gravels may not have been laid down during or after the onset of the first phase of the Riss Glaciation. These gravels were undoubtedly accumulated under temperate conditions, but it is possible that, owing to its position, Britain was dominated by Atlantic weather during the weak Riss I or Alpine Glütsch Glaciation, in which case the Great Interglacial was not effectively terminated here until the maximum or Riss II Glaciation.

Thus, although the fallow deer¹ (*Dama*) and most of the other large mammals in the Swanscombe Middle Gravels indicate beyond doubt that interglacial conditions prevailed in the Thames Valley during their deposition, it must be admitted as a possibility that in highlands, particularly in higher latitudes, glaciers were already beginning to re-advance. This may well have caused a shift in the distribution of cold-tolerant forms such as the lemmings, with the result that they spread into regions where, hitherto, they had been unknown under fully interglacial conditions.

The occurrence of a thin solifluxion wedge between the sands of the Upper Middle Gravel and the overlying Upper Loam (Fig. 4) supports the conclusion, based on the faunal evidence, that these deposits belong to the closing phase of the Great Interglacial period, perhaps even contemporary with the recrudescence of glacial conditions elsewhere.

The molluscan fauna from the Swanscombe gravels was studied by Mr. A. S. Kennard who has reached two interesting conclusions. First, that, judging by the land-snails in the Middle Gravels, the country in immediate contact with the river was entirely grassland. Secondly, that, whereas during the deposition of the Lower Gravel (with Clactonian industry) the Thames and Rhine had been separate, during the interval represented by the land-surface on the Lower Loam they had become connected. The result was that Rhenish species of freshwater Mollusca began to colonise the Thames Valley. Rhenish species are said to be particularly well represented in the fauna of the Upper Middle Gravel.

When one considers the distribution of Acheulian industries in Africa and recalls the fact that they occur not only in interglacial

¹ One item in the list of Mammalia recorded by Stopes (1904) in the gravels of the Ingress Vale pit at Swanscombe has puzzled many students in recent years—the record of reindeer ('*Cervus tarandus*'). The small fragments of antler on which this determination was based are fortunately preserved in the Stopes Collection at the Geological Survey Museum. When they were re-examined by the late Mr. A. S. Kennard about 1946, he had no doubt that they were referable to *Dama clactoniana* which is common in both Lower and Middle Gravels at Swanscombe. It is now generally supposed that the Ingress Vale fauna, which includes *Trogontherium* (a Villafranchian survival), belongs to the same horizon as the Lower Gravel of Barnfield pit.

river-gravels, but also in the Older Loess of France, it begins to appear very probable that the hand-axe people, like the Australian aborigines, were mainly adapted to life in open grassland, rather than to wooded country. Perhaps the Clactonian industry represents the facies of Lower Palaeolithic culture which was more related to forest life.

7. DATING OF SWANSCOMBE MAN

In general terms there is no doubt that the Swanscombe skull dates from the closing stage of the Mindel-Riss or Great Interglacial, but it remains for future research to establish its precise time-relation to the weak pre-Rissian glacial advances.

Estimation of the antiquity in years of fossil human remains always makes a strong popular appeal, but all such estimates, except within the practical range of the radio-carbon method (30,000 years), are at present so unreliable that they are almost devoid of scientific value. On the basis of the 'Astronomical Theory' of glacial fluctuations, Professor F. E. Zeuner has suggested that the Swanscombe skull may be 275,000 years old. Since it has been established that this fossil antedates the Riss II Glaciation, and since all estimates of the age of the latter exceed 100,000 years, one may at any rate reasonably state the antiquity of this specimen as 'at least 100,000 years.'¹

8. NATURE OF SWANSCOMBE MAN

The Swanscombe skull (Figs. 8, 11) is probably that of a female, because the muscular markings are slight in relation to its size and thickness. Its cranial capacity, estimated to have been about 1325 cc., is close to the average of modern female skulls. The skull was quite short and, with an estimated cephalic index of 78, approached the brachycephalic condition (a point of similarity with some early Neanderthaloid skulls). The sutural margins show no sign of closure except at one point on the sagittal suture where closure usually begins at the age of about twenty in modern Europeans. We may conclude that the Swanscombe woman died or was killed in her early twenties (but, judging by women of that age in primitive hunting tribes of the present day, we would probably be wrong if we visualised her as very youthful in appearance).

Professor Le Gros Clark and Dr. Morant reported that, in so far as it is preserved, this skull shows no characters which would definitely exclude it from *Homo sapiens*, but that it does show a number of features which would be exceptional in a modern skull. Like most Lower Palaeolithic skulls it has an extremely broad occipital bone. In fact the breadth of this bone is close to the limit of the range of variation in modern female crania. The bones are excep-

¹ By the same token I suggest that the antiquity of the Fontéchevade and Piltdown skulls, probably dating from the Riss-Würm Interglacial, is perhaps best stated as 'at least 50,000 years'.

tionally thick, almost as thick as those of the Piltdown skull, probably more massive than any known female skulls of the present day other than those thickened by some pathological state, such as Paget's disease.

In view of its incompleteness, the failure to find any feature distinguishing it from skulls of *Homo sapiens* is not sufficient reason for identifying it as a member of that group. It has been shown that the corresponding bones of a classic Neanderthal skull, the Rhodesian skull and a skull of *Pithecanthropus* can be distinguished from *Homo sapiens* by measurements alone. On the other hand, the early Neanderthaloid skull found at Steinheim, near Stuttgart, in deposits of probably Riss I/II, age can *not* be distinguished from



FIG. 8.—The Swanscombe skull bones articulated together and seen from above. They have been superimposed on an average contour from the top view of a number of modern skulls. Half natural size. Based on *Le Gros Clark and Morant*. del. D. E. Woodall.

The two faint depressions (like fingerprints) on the parietal bone probably mark healed scalp wounds or ulcers

Homo sapiens on the basis of its parietal and occipital bones; and yet its frontal bone has a strong brow-ridge, or supraorbital torus (Fig. 9). Thus it has to be admitted that the missing parts of the Swanscombe skull may have been of such a form as to exclude it from the ranks of *Homo sapiens* as generally understood. Morant stated that, in his opinion, the 'occurrence of abnormally thick parietal and occipital bones in a specimen of this size . . . suggests forcibly not only that the missing frontal bone was abnormally thick, but also that it probably possessed a more massive supraorbital region than any modern specimen'. He ventured the opinion that the Swanscombe and Steinheim skulls may have belonged to the same group. Certainly they are very nearly of the same geological age.

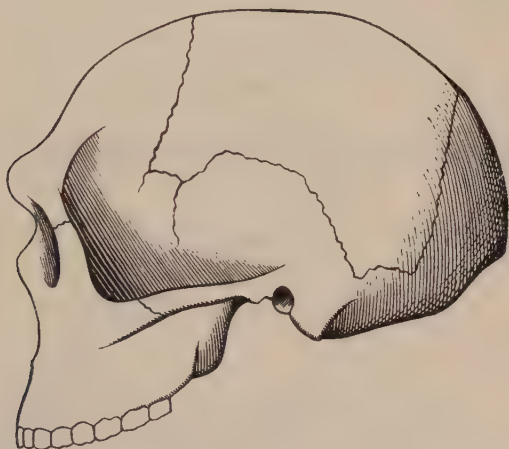


FIG. 9.—Early Neanderthaloid skull from Steinheim, near Stuttgart. Slightly restored. One-third natural size. *After Weinert.*

It is noteworthy, however, that the parietal and occipital bones of the type Piltdown skull are even thicker, and yet its frontal bone (like that of Piltdown II) is massive without showing a supraorbital torus. There are a number of features of the Swanscombe skull which are extraordinarily reminiscent of the Piltdown crania. Some of these were pointed out by Marston in his first description of the skull (1937); and they were discussed in further detail by Sir Arthur Keith (1938–9). Marston's recent researches have again raised the question of whether the Piltdown mandible and the Piltdown I braincase belong to a single creature or not; but that need not deter us from counting the *braincase* as that of a fossil man of probably Third Interglacial age. Most of the pieces of the Piltdown I braincase were found loose on the spoil-heaps, but fortunately it is recorded that

one small piece of the occipital bone was found *in situ* in the basal layer of dark red gravel together with remains of beaver having the same low fluorine content. This proves beyond doubt that the brain-case is a genuine fossil belonging to the Piltdown river-gravel, and that being the case it cannot be younger (nor is it likely to be older) than the 50-ft. Terrace, which is for the most part attributed to the Third Interglacial.



FIG. 10.—Fontéchevade skull (II) showing assumed outline of frontal sinus (dotted); frontal profile (broken line) is based on Piltdown II. One-third natural size. *After Vallois.*

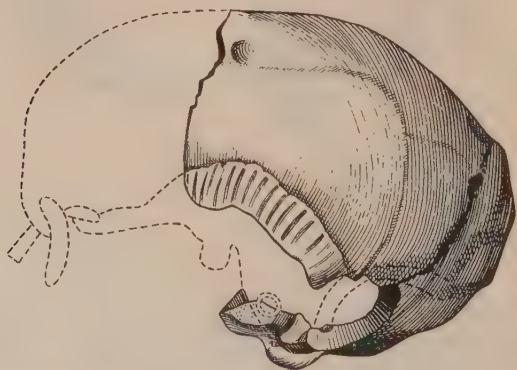


FIG. 11.—Swanscombe skull in profile as restored by Sir Arthur Keith. One-third natural size.

The presence or absence of a supraorbital torus may not be so important for assessing relationships in fossil Hominidae as it was at one time believed to be. Several factors are involved in its development, the principal one being the distribution of the stresses due to powerful mastication, which subject the frontal bone to considerable strain when the cranial base is long and when the forehead is receding. It may be that, in short thick-walled skulls with moderately

elevated vaults, the stresses imposed by mastication were so distributed that the supraorbital torus became reduced or failed to develop.

Whether the Swanscombe skull had a supraorbital torus or not remains uncertain, but the basi-occipital bone shows loculi due to a backward extension of the sphenoidal air-sinuses (Fig. 8), and, according to Professor Le Gros Clark, this suggests a very massively developed face.

In attempting to decide the relationship of Swanscombe Man to other Lower Palaeolithic men, it is important to bear in mind the many indications that human evolution has not proceeded along a single line through an orderly sequence of types. Studies of the European Neanderthal skulls has shown that the earlier have more features in common with modern man than the later. This strongly suggests that the Neanderthals were isolated in western Europe during the Last Glaciation, and, probably through a combination of intensified selection and genetic drift, became modified along very aberrant lines and then died out. Some of the less specialised Neanderthaloids to the south and east, for example the Mount Carmel men, show a mosaic of '*sapiens*' and 'neanderthal' characters, and it is possible that the 'races' of modern man evolved from stocks of that general type.

Professor Vallois has pointed out the features in common between the Swanscombe skull, the Piltdown skulls (I and II) and the two incomplete crania of Third Interglacial age found with a Late Clactonian (Tayacian) industry at Fontéchevade in the Charente (Fig. 10; cf. Fig. 11). It may be that these were members of a lineage, perhaps of African origin, in which '*sapiens*' characters were predominant at an early date; but further discoveries will have to be made before we shall know whether they should be regarded as directly ancestral to any ethnic groups living today, or simply as ecgonomorphs.¹

One would certainly be wiser to refrain altogether from attempting to draw any detailed conclusions from the morphology of the interior surfaces of the Swanscombe skull bones, already described in detail and with great caution by Professor Le Gros Clark; for, as the late Professor Weidenreich once remarked, the interpretation of endocranial casts is no more reliable than any other form of phrenology. However, it is perhaps significant that the occipital cortex, which includes the visual area, was richly convoluted in this early type of man. Is it possible that this was a development related to the extremely acute powers of vision required by primitive hunters adapted to life in open country?

Much more can be learnt about the quality of the brains of fossil men from their culture than from their endocranial casts. Henry

¹ Forms which anticipate a later stage in the evolution of a group without being necessarily directly ancestral (ἐκγονος = descendant, μορφή = form).

Stopes was one of the first to point out that Acheulian hand-axes from widely separated areas were commonly identical in form even when made of materials with quite different flaking qualities. This suggests that the *idea* of making an implement in a particular form was transmitted by tradition across vast distances, and it implies that there was no basic difference in intellectual capacity between, shall we say, the hand-axe makers of the Transvaal and the Thames Valley. Yet the greater part of the culture of Early Palaeolithic peoples, in wood and other perishable materials, has been irretriev-

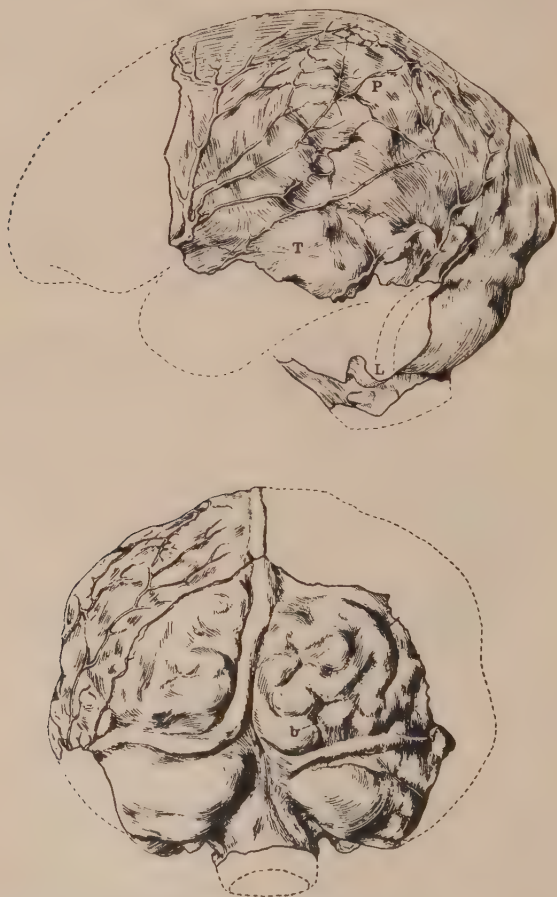


FIG. 12.—Endocranial cast of the Swanscombe skull bones. $\frac{7}{18}$ natural size. Above, lateral view; below, posterior view. After W. E. Le Gros Clark.
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ably lost, and if, with the aid of a Wellsian time-machine, we could actually meet Acheulian people in South Africa and compare them with their contemporaries at Swanscombe, we might be astonished by the differences in their culture and even in their physical type. To assume that they were identical because their few imperishable articles of equipment were of the same form is not justifiable in the light of modern ethnographical parallels; and when we humanise Palaeolithic archaeology by speaking of the 'Acheulian people', we should bear such reservations in mind.

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THE PLIOCENE-PLEISTOCENE BOUNDARY IN THE EAST OF ENGLAND

By P. G. H. Boswell, F.R.S., F.G.S.

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ABSTRACT.—At the XVIIIth Session of the International Geological Congress in 1948, a Commission was appointed to advise on the definition of the Pliocene–Pleistocene boundary. The changes in the classification of the Pliocene deposits of the East of England that would be necessitated, if the Commission's recommendation is adopted, are now reviewed. It appears that two courses are feasible: (a) to draw the boundary at the unconformable base of the Red Crag, or (b) to regard the Red Crag as Plio-Pleistocene and abandon the attempt to locate an imaginary boundary within this continuous series of deposits, the Mollusca of which yield evidence of progressive climatic deterioration. The former course is considered preferable on the ground of 'ease of application'. In particular, it is noted that the placing of the boundary, as has been suggested, between the middle and upper divisions of the Red Crag (assuming that these divisions could be precisely delimited) would leave beds containing remains of horse and elephant in the Pliocene, which would be contrary to the Commission's intentions.

1. INTRODUCTION

ON numerous occasions, field meetings have been arranged to enable members of the Association to study the Pliocene and Pleistocene deposits of the east and south-east of England: many important papers on these formations have also appeared from time to time in our PROCEEDINGS. Members have doubtless followed with interest the renewed efforts made at the XVIIIth Session of the International Geological Congress in 1948 to secure international agreement on the principles that should guide us in fixing the boundary

between the two Series. The Report of the Commission that was appointed to consider the problem has since been published, and we learn that a satisfactory measure of agreement was reached. Geologists in various parts of the world will now be examining the implications of the Commission's recommendation for their own particular areas; therefore, a few notes relative to the succession in the east of England may not be inappropriate to the Association's PROCEEDINGS. Perhaps I may be allowed to introduce a personal note here and to recall that, whilst I was engaged on the investigation of the Craggs of East Anglia, certain of my excavations were visited in 1906 by a party of members (*Proc. Geol. Assoc.*, 19, p. 459). By accepting the complimentary invitation to join the Association, I began a long and close participation in its activities, for which privilege I have ever been grateful. My excuse for returning to a subject, which I have virtually abandoned for twenty years by force of circumstances, is that I appear to be the sole remaining link in matters Pliocenic with those well-known pioneers, Alfred Bell, F. W. Harmer, P. F. Kendall, E. T. Newton, Clement Reid and William Whitaker, all of whom helped and encouraged the raw recruit. Meanwhile, one has to record with regret that field evidence in East Anglia is now considerably less than it was half a century ago: since then, exposures have been steadily deteriorating and, indeed, disappearing entirely.

Although the problem of the Pliocene-Pleistocene boundary has for many decades engaged the attention of specialists in palaeontology and stratigraphy, a fresh impetus has been given by advances in prehistoric archaeology, since they brought again to the fore the burning question of the antiquity of Man, the answer to which depended in part on opinion regarding the origin of the flaking of flints and bones, and in part (since we are influenced by our conventional nomenclature) on stratigraphical terminology. 'Pleistocene Man' would have been much less challenging to the old order than 'Pliocene Man'.

2. THE NEW PROPOSALS

In their report,¹ the Commission of the Congress agreed that a type-area should be selected where the Pliocene-Pleistocene boundary (Tertiary-Quaternary) could be drawn in accordance with stratigraphical principles—that the boundary should be based on changes in marine faunas, and that the classic Italian area would serve best. The Commission definitely recommended that the Lower Pleistocene should include, as its basal member in the type-area, the Calabrian formation (marine) together with its terrestrial (continental) equivalent, the Villafranchian, and noted that this usage would place the boundary at the horizon of the first indication of climatic deterioration in the Italian Neogene succession.

¹ A useful summary of their deliberations has been given by Professor W. B. R. King and Dr. K. P. Oakley in *Nature*, 163, 1949, p. 186. The papers presented on the subject have been published in the Report of the Congress, Pt. IX, 1950.

Contributors to the discussion expressed different views about the implications of these proposals on the classification of the strata in the east of England. For example, Mr. D. F. W. Baden-Powell thought that the boundary should be placed at either the base of the Norwich Crag or that of the Red Crag, preferably the latter. Professor I. M. van der Vlerk located it between the middle (Newbournian) and upper (Butleyan) divisions of the Red Crag. Dr. Hallam L. Movius, Jr., in a paper published recently (1949, table, fig. 7), has put it between the lower (Waltonian) and middle (Newbournian) divisions of the Red Crag, but without comment. Obviously there is a case for further discussion, and perhaps investigation. In the meantime, I offer some observations in favour of making the base of the Red Crag the lower limit of the Pleistocene: any attempt to locate a time-plane within the formation seems to me, from the very nature of the deposit, to be doomed to failure. And to place it between the middle and upper divisions, supposing it could be done, would leave in the Pliocene certain deposits containing remains of elephant and horse, but this would not accord with the Commission's intentions, which were to place the Villafranchian (characterised by a fauna including *Elephas*, *Equus* and advanced bovines) in the Pleistocene.

3. THE STRATIGRAPHY OF THE CRAG DEPOSITS

For many years past, geologists have expressed the opinion that the boundary should be determined by three lines of evidence, namely (as G. E. Pilgrim, for example, put it in 1944) widespread tectonic action, climatic degeneration and invasion of the area by new forms of life—there usually being a close connection between the last two. The first criterion cannot be, *ipso facto*, of world-wide application, but we shall all agree on the desirability that the type-area or areas (and East Anglia, for various reasons, will remain *a* type-area, even though Italy provides *the* type-area) should display the appropriate unconformity.

(a) **The stratigraphical break.**—Fortunately, all the desiderata are satisfied in East Anglia if the boundary is placed between the Coral-line and Red Crag, that is, all the patterns (to use Dr. A. T. Hopwood's concept) combine to yield a picture with a minimum of blurring. A flagrant unconformity is visible between the two formations and is accompanied by important changes in the lithology of the respective deposits and in their fossil-content. As will be noted below, the oldest Red Crag affords evidence of the first substantial incursion of northern forms and thus, assumably, of the onset of cold conditions in the area. In saying this, we base our inference on a balance of probabilities, since uplift of the land on the south and the breaking of a barrier on the north could produce these conditions, but the arrival of a flood of individuals now confined to northern waters suggests climatic deterioration.

Another unconformity in the Crag series has been mentioned by Mr. Baden-Powell who speaks of a marked stratigraphical break between the Red and Norwich Crag. This is not in accord with my experience. The Norwich Crag follows on northwards from the Red Crag and, in consequence, we have always found difficulty in distinguishing the two formations in the Aldeburgh area, and in assigning the Crag of mid-Suffolk, met with in well-sinking or exposed in the upper reaches of the valleys, to one or other formation. A stratigraphical break at the base of the Norwich Crag does not develop until the deposit oversteps, in the familiar geological manner, on to the Eocene or Chalk of Norfolk.

(b) **The subdivisions of the Red Crag.**—It will be remembered that F. W. Harmer divided the Crag into a series of 'zones' which he named after certain East Anglian localities and species of Mollusca. He styled the Coralline Crag the Gedgravian (zone of *Isocardia cor*), and divided the Red Crag into three 'zones', named after supposedly representative localities, Walton-on-the-Naze, Newbourn and Butley (zones of *Neptunea contraria*, of *Macra constricta* and of *Cardium groenlandicum*, respectively). These three divisions, and the succeeding Norwich Crag (Icenian) were, he emphasised, never seen in superposition, but replaced each other northwards. Although he did not actually use the varying percentages of northern, southern, 'living-in-British-seas' and extinct Mollusca in classifying the deposits, he later followed Lyell's lead by producing a table showing the distribution of characteristic and abundant species in support of his system of subdivision. Before his time, two divisions, the Older and the Newer, had served for the Red Crag. Subsequently, Bell (1912, p. 296) distinguished the upper part of the Coralline Crag as the Boyton 'zone', and Harmer subdivided his Waltonian into three 'horizons'—named after the Essex localities—Walton, Beaumont and Oakley—in order of decreasing age of the faunas. The relatively large area of well-exposed Crag, lying between the estuaries of the Stour and the Orwell, was, in the absence of precise knowledge, assigned to neither the Waltonian nor the Newbournian, but received a question-mark on his maps, to be later deleted when I had worked over the deposits. Harmer correlated the Waltonian with the Scaldisian of the Netherlands, the Beaumont and Oakley Beds together with the Poederlian, and the combined Newbournian and Butleyan with the Amstelian. A useful account of his ideas will be found in the pamphlet he prepared for the Long Excursion of the Association in 1902, and in 1908 in the Jubilee Volume, *Geology in the Field*. The latest expression of his views is to be found in the introduction to the second volume of his *Monograph on the Pliocene Mollusca*, published by the Palaeontographical Society (1920).

It is significant that Harmer was unable to show boundary-lines on his maps between his various Red Crag 'zones', but was content to indicate generally the area that each occupied by inserting the words

'Waltonian' south of the Stour estuary, 'Newbournian' between the estuaries of the Orwell and Deben, and 'Butleyan' between the Deben and the Alde. The Icenian was delimited north of the Alde. This was a matter of convenience only, since the estuaries are post-Neolithic features, and in places are transgressed by the 'zones'. The idea may thus have arisen from the maps that boundaries were present. Unfortunately, also, the dividing-lines that were inserted in some (though not all) of his tables of strata have the effect of obscuring the characteristic continuity of the Red Crag as a whole. Nobody has yet, in fact, been able to discover on the ground a boundary between any two of the subdivisions or between the Red Crag and the Norwich Crag. I am sorry to labour the point, but it is critical.

Although the difficulty of deciding on a particular plane in a continuous series of deposits which will serve as a stratigraphical boundary is one frequently encountered in geology, it seems to be intensified in the case of a laterally-disposed deposit of drifted material like the Red Crag. Those familiar with the formation will remember that numerous exposures are unfossiliferous; many show only comminuted shell-material; and others contain a limited assemblage of species which is not diagnostic of one or other subdivision. In such a drifted deposit, the fossils from which are often identified by fragments, the possibility of derivation from older horizons towards the south has always to be borne in mind. An interstratal boundary becomes imaginary, and should only be adopted to separate important divisions like the Pliocene and Pleistocene Series, if there is strong evidence in support. Since it is agreed that this evidence should be primarily that of climatic deterioration, the faunal changes in the subdivisions of the Crag will now be reviewed.

The investigation of faunas always carries with it an element of chance. A particular worker may discover a rich seam concealed from his predecessors—as Kendall did at Walton, Harmer at Oakley, or Bell at Boyton—which may upset the smooth run of graphs that have been prepared for the purpose of demonstrating the progressive climatic change. Further, it should be emphasised that detailed lists of fossils have been published for only a few localities. Since Reid's review in 1890 of the earlier researches, Kendall has given us the most complete list from Walton (1931, p. 413), with due acknowledgment to R. G. Bell for his identifications. Harmer did not, however, to my knowledge, publish a complete list of his remarkable finds at Oakley, or one for Beaumont. We have a list for Bentley (Boswell, P. G. H., 1924, p. 214), but only old records for Newbourn, which in my experience has not been one of the best collecting-grounds, unlike the neighbouring localities of Foxhall, Waldringfield or Felixstowe. Also, A. Bell (1912, p. 302) produced a list for the Coralline Crag of Boyton.

When use is made of tables showing the relative proportions of northern, southern, extinct, etc. species in the molluscan faunas of

the various Crag deposits, such as the tables prepared by Reid (1890, p. 145) or Harmer (1900, p. 725), the figures from which are still being quoted in recent publications, it should not be forgotten that subsequent work has greatly modified the results and made the compilation of new tables highly desirable. The publications by Harmer (1914-25) and Kendall (1931), referred to above, provide new data which can be interpreted in the light of the greatly increased knowledge of the number and range of living forms. But Harmer dealt only with the Gastropoda and Scaphopoda (except for a few terrestrial Pelecypoda), and Kendall described the fauna from Walton only. Thus we are not yet in a position to compile new tables for all the Mollusca, but I have attempted an analysis of the records of Gastropoda from Harmer's Monograph, in order to discover how much evidence is yielded by this class in favour of continuous climatic change.

If such a distribution table is entitled, as Harmer's was, 'Characteristic and abundant species only', the subjective element must have twice influenced the compilation, first in the matter of the identifications, and secondly in the selection of illustrative forms. For the latter, statistical analyses are desirable. In the table below, all the recorded species have been taken into account, but not varieties, the inclusion of which would have increased the proportion of northern forms. General experience indicates that the number of species of Pelecypoda in the Crag is usually considerably smaller than that of Gastropoda, but whether or not their inclusion would have produced an appreciable difference in the balance of the table, has still to be determined. My opinion, for what it is worth, is that the result would not have been greatly different, although the percentage of northern Pelecypoda appears to be relatively smaller than that of the northern Gastropoda. A fresh analysis is also desirable for the reason that, during the last few decades, the impressions have arisen that the Waltonian is (a) more closely allied to the Coralline Crag than was formerly suspected, and (b) marked by a sudden increase in the number of species and individuals of northern character. That the contradiction is only apparent will be evident from the table.

DISTRIBUTION OF MARINE GASTROPODA IN THE CRAGS

	Northern per cent	Southern per cent	Not known living per cent	Total no. of species
Icenian	26	0	28	98
Butleyan (Red Crag)	21	2	40	163
Newbournian (Red Crag)	12	7	53	226
Waltonian (Red Crag)	16	11	48	352
Coralline Crag	4	12	57	303

Breaking down the Waltonian figures, we have:—

Oakley Horizon	16	12	51	316
Beaumont Horizon	10	6	61	79
Walton Horizon	9	10	48	181

A comparison of this analysis with those previously published, shows that the most noteworthy difference is the increase in the number of species 'not known living' (which is a better expression than 'extinct'). This is a reflection of more intensive studies. The proportion of northern species in the Coralline Crag has been increased from about 1 to 4 per cent. The smaller proportion of northern forms now recorded from the Newbournian is, I believe, due to two causes—the restricted faunas found at many localities and the lack of recent work at sites known to be profitable. The proportion of northern species from the Waltonian, thanks to the list from Oakley, has been greatly increased: this result, in the light of our experience that the number of individuals as well as species is substantial, is significant in relation to the problem of delimiting the base of the Pleistocene.

The realisation of the need for further field-work on the Crag, and for revision of the earlier collections and correlations, brings to mind the plea made recently by Dr. H. L. Movius, Jr. (1949) for the re-investigation also of the Calabrian Mollusca, in order that a more satisfactory correlation may be effected with the faunas of other European deposits.

(c) **First appearance of elephant and horse.**—Although remains of ox have not been found in East Anglian deposits older than the Cromer Forest Bed, teeth of its companions, the elephant and horse, have been obtained from the Red and Norwich Crag. E. T. Newton and C. Reid collected the records together in Geological Survey Memoirs sixty years ago, and Dr. A. T. Hopwood has more recently (1937, p. 900; 1940, p. 81) reported in detail on the remains. These records appear to have been overlooked by the contributors to the Congress discussion who referred to the English deposits.

Dr. Hopwood gave an account of ten teeth of caballine horses from the Red Crag, all unrolled and contemporaneous with the deposit. In five instances, unfortunately, the specimens were labelled only 'Red Crag, Suffolk', and in one, 'sands over Crag, Suffolk'. The remainder are more precisely localised, having been obtained from Bawdsey, Felixstowe and Woodbridge. The Crag at Bawdsey is, I consider, younger than that of Newbourn, but older than that of Butley; however, it is doubtless best grouped with the latter. The Crag at Felixstowe and Woodbridge belongs assuredly to the Newbournian division.

Most of the vertebrate remains from the Crag were collected during the working of the basement-bed for phosphate (coprolite). Since the deposits were richest and were exploited mainly in the area between the Orwell and Deben estuaries, it seems probable that the vaguely localised teeth came from the Newbournian division. Although the bone-bed occurs also beneath the Waltonian Crag, it is poorly developed, and was not worked. We have no records of its vertebrate fauna.

Teeth of '*Elephas meridionalis*' were found at Trimley and Falkenham. E. T. Newton (1891) noted also a record from Felixstowe, but the tooth in question could not be traced. The Crag at all these localities belongs to the Newbournian.

There can be no question, therefore, but that the remains of *Equus caballus*, *E. robustus* and '*Elephas meridionalis*' occur in deposits of the Red Crag older than the Butleyan.

In the course of discussing the boundary problem, the late G. E. Pilgrim (1944, p. 29) deprecated the selection of 'a few important and widely-spread invading types of mammals on the assumption that they arrived simultaneously in every part of Europe. Such suggested genera are *Leptobos*, *Elephas* and *Equus*.' His preference lay in selecting an important time-break, or period of great tectonic activity, correlated with the onset of colder conditions. I had the privilege of discussing the problem with him at some length during the last months of his life, while he was preparing the paper that was published posthumously. Although he believed that the ox, elephant and horse arrived in Europe in Upper Pliocene times, he came to the conclusion, perhaps influenced by our exchange of views, that the Pliocene-Pleistocene boundary was best placed between the Coralline and Red Crag.

4. SOME RESULTANT CONSIDERATIONS

The removal of the Red Crag from the Pliocene to the Pleistocene will necessitate some modification of existing views about the dating of certain other English deposits, of earth-movements, glaciation and evidence of primitive man. Although these matters may not be relevant to the location of the boundary in East Anglia, brief mention of them at this stage will doubtless result in their being kept in mind.

(a) **Netley Heath deposits, near Guildford, Surrey.**—In the sandy and gravelly beds that rest high up on the Chalk escarpment (500 to 670 ft. O.D.), believed by the Geological Survey to be Pleistocene (H. G. Dines, *et al.*, Aldershot Memoir, Sheet 285, 1929, p. 110), certain included masses of ferruginous sands, etc., were found to contain numerous casts of Mollusca. Mr. C. P. Chatwin's investigation (1927, p. 155) of these remains proved that the fauna was of Red Crag age. He noted that thirty-one specimens out of a total of 111 consisted of the 'extinct' Pelecypod *Corbulomya complanata*, a species which, in my experience, occurs throughout the Red Crag as occasional specimens. The general assemblage is comparable with that of the Waltonian or Newbournian division. If the Red Crag is referred to the Pleistocene, the Netley Heath beds and related deposits on the Weald and Chiltern Hills (e.g. Rothamsted, near Harpenden, for an account of which see Dines, H. G. and C. P. Chatwin, 1930) yield evidence of a still older high-level Pleistocene stage. Their age is then indubitably Pleistocene, but the consequen-

tial re-dating of the erosion-surfaces in south-east England may require some revision, if only in terminology.

(b) **Dewlish Gravel, near Dorchester.**—The presence of remains of '*Elephas meridionalis*' and *Equus robustus* in the Dewlish gravels led to their being assigned, though not without some difference of opinion, to the Pliocene. Difficulties are resolved if these mammals are regarded as of Pleistocene age.

(c) **St. Erth deposits, near Penzance, Cornwall.**—Within living memory, only the uppermost unfossiliferous clayey sands have been exposed at St. Erth. The underlying blue clays yielded to P. F. Kendall and R. G. Bell (1886) an interesting fauna which appeared to be intermediate in age between the Red and Coralline Crag and to have southern affinities. Harmer's re-investigation of the Gastropoda led to a considerable increase in the number of species identified (namely, 174). My analysis shows that, of these, the forms, 'not known living' account for 54 per cent, and the southern, 22 per cent; also, a single northern species was recorded. Comparison of these figures with the percentages given in the table on p. 306 suggests that the age of the St. Erth beds is similar to that of the Coralline Crag, and that they should remain in the Pliocene.

(d) **Diastrophism.**—Earth-movements were in operation during later Crag times and, since the deposits are of similar lithic character throughout, must have proceeded *pari passu* with sedimentation. These conditions resulted in the accumulation of 170 ft. of Norwich Crag in the Lowestoft area, and of 150 ft. of comminuted crag of doubtful age in mid-Suffolk and Norfolk, the underlying Chalk being folded along a SW.-NE. axis to produce a syncline more than 200 ft. in depth in the latter area (Woodland, A. W., 1946, p. 18 and figs. 7 and 8). The north-easterly pitch of the fold may have been the cause, at least in part, of the elevation of the Red Crag in Surrey to its present level. The sinking on the other side of the North Sea, (e.g. as shown in the Amsterdam area) extended to a depth of 1100 ft.

Under the existing scheme of classification, these movements were regarded as the continuation in time and space of what Grenville Cole picturesquely termed 'the outer ripples of the Alpine storm'. Under the new scheme, they would indicate that North-west Europe, like parts of North America, East Africa, India and the Far East, came under the influence of Pleistocene diastrophism. Although the East Anglian area is one which may well have been the scene of an interplay between isostatic and eustatic movements, according as the ice-sheets in polar regions waxed and waned, a belief in the persistence of independent tectonic movements had already become necessary in order to explain the levels and character of the post-Icenian deposits. The difficulties felt by Professors van der Vlerk and Woldstedt in accounting for the latter, seem to me to arise from too exclusive an adherence to the eustatic theory.

(e) **Length of the Pleistocene period.**—The placing of the lower limit

of the Pleistocene at the base of the Red Crag will not necessarily lead to a great increase in our estimate of the time occupied by the Pleistocene. The sandy and gravelly deposits of the Craggs could accumulate rapidly: a few thousands of years would appear to be ample. Whether or not the rate of evolution of species of Mollusca or mammals requires a considerable extension of the supposed length of the period (at present estimated by extrapolation with very different results by different writers), I leave to others more competent than I to judge.

(f) **The earliest glaciation.**—There is no evidence—at least, no direct evidence—that any of the Crag deposits were laid down during a glacial episode. The evidence for climatic deterioration is two-fold: it is provided by the faunal change already referred to, and by the presence in the basement-beds of the Craggs (or, less commonly, in the deposits themselves) of far-travelled boulders, some of unknown origin and some definitely derived from the north (Double, I. S., 1924, p. 343). These erratics afford no better evidence of a glacial episode than do those dropped from melting icebergs at the present day in the North and South Atlantic Oceans (Boswell, P. G. H., 1936, p. 153).

(g) **Early man.**—Finally, a question may be asked about the bearing of this discussion on the problem of Pliocene man. It is probably familiar to all that the great majority of the flints and bones, believed by J. Reid Moir to have been humanly-fashioned, came from the basement-beds of the Red and Norwich Craggs, that a few came from within the Crag, and that only two specimens were obtained from the Coralline Crag, one from below it and the other from within it. Were it not for the existence of the last-mentioned two specimens, 'Pliocene man' (supposing that the flaking is accepted as human) would become 'early Pleistocene man'. Therefore, these two specimens should be again scrutinised, since a consensus of archaeological opinion on the nature of the flaking becomes of critical importance. The specimens were figured by Moir (1935, fig. 8 and pl. 26), but the illustrations will, perhaps, hardly convince geologists. One additional matter deserves consideration. A number of the flaked flints from below the Red Crag bear white, calcareous, sandy incrustations which Dr. J. D. Solomon believed to be similar to Coralline Crag material. If this be true, the flints were derived from the Coralline Crag, and the flaking must have pre-dated or been contemporaneous with that deposit. The problem needs re-investigation before the existence of pre-Pleistocene man in East Anglia can be regarded as proven.

5. CONCLUSION

The foregoing observations indicate the following:

1. A strong unconformity is found at the base of the Coralline Crag. The fauna is predominantly southern in affinities, but a few northern species of Mollusca make their appearance in the deposit.

2. Another strong unconformity separates the Red Crag from the Coralline Crag, and the two deposits have very different lithic characters. The earliest division of the Red Crag yields evidence of the arrival of numerous northern Mollusca. Henceforward, these increase, in numbers of species and individuals, throughout the continuous deposit of the Red and Norwich Crags. Many erratic boulders occur.

3. Remains of elephants and caballine horses appear for the first time in the middle division of the Red Crag.

If the classification of the deposits is to be brought into line with the proposals of the Commission appointed by the XVIIIth International Geological Congress, one or other of two courses can be adopted:

- (a) to place the boundary at the base of the Red Crag, or,
- (b) to regard the Red Crag as Plio-Pleistocene and abandon the attempt to locate a boundary-plane within it.

In the present state of knowledge, the former course seems to me to be preferable—on the principle of ‘ease of application’ (*pace* A. T. Hopwood).

NOTE.—When this paper was about to go to press, the Editor kindly drew my attention to Dr. Robert Lagaaij’s recently published monograph on ‘The Pliocene Bryozoa of the Low Countries and their bearing on the marine stratigraphy of the North Sea Basin’ (*Meded. Geol. Sticht.* ser. C., 5 (5), 1952, Maastricht). As a result of his revision of the palaeontology of British and Continental species ranging from the Helvetian-Tortonian to the Waltonian, and of the distribution of living forms, he is strongly of opinion that the Scaldisian (*s.s.*) of the Netherlands is to be correlated with the British Gedgravian, the Lower Amstelian (= Poederlian) with the Waltonian, and the Upper Amstelian with the Newbournian and Butleyan. From the evidence he has adduced, he considers that the Pliocene-Pleistocene boundary should be placed at the base of the Waltonian.

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THE USE OF ACETIC ACID IN DEVELOPING BRACHIOPOD SHELLS

By H. M. Muir-Wood, D.Sc. and Ellis F. Owen
(*Dept. of Geology, British Museum (Nat. Hist.)*)

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THE use of acetic acid to free Cambrian brachiopods with chitino-phosphatic shells from a calcareous matrix, was described by Prof. W. C. Bell, of Minnesota, in 1948. Although this technique has been employed in the development of fossil fish and reptile skeletons at the British Museum (Natural History) by H. A. Toombs (1948) and A. E. Rixon (1949), its use for invertebrates seems to be little known in this country.

Experiments have now been made by the authors on Cretaceous brachiopods, especially rhynchonellids, in which the shell, normally of calcium carbonate, has been altered while the calcareous matrix has remained unchanged. In dilute (5 per cent) hydrochloric acid such shells are usually completely dissolved or broken down, but if immersed in 15 per cent acetic acid the matrix is dissolved and the shell remains with the two valves separated and the crura often in a perfect state of preservation. Excellent results were obtained with specimens from the Cenomanian of Warminster, Wiltshire; Lulworth Cove, Dorset; Chardstock, Wilmington, and White Cliff, Beer, Devon; Bléville and Le Havre, France, and from the Ciply Chalk, Belgium.

These specimens, mostly from the Lower Chalk, were at first thought to be altered by phosphatisation of the shell since the matrix contained much glauconite, but chemical analysis of one specimen showed only 0.6 per cent of phosphate. It was then decided to have a complete analysis made of one of these altered rhynchonellid shells which had broken down in hydrochloric acid. A Cenomanian specimen (B. 8363)¹ from Warminster, Wiltshire, was therefore freed from matrix and divided into three parts. One part was broken down with hydrochloric acid leaving only a thin film, the second part proved to be insoluble in acetic acid, and the third part was crushed to a powder and analysed. A rhynchonellid shell (B. 93141) from the Upper Chalk, *Belemnitella mucronata* Zone of Norwich, Norfolk, was analysed for comparison.

These analyses were carried out in the Department of Mineralogy, British Museum (Nat. Hist.), by Mr. D. I. Bothwell, by the courtesy of Dr. M. H. Hey who supervised the work.

It is of interest that a shell with such a high percentage of silica

¹ The Specimens marked B. 8363 and B. 93141 are registered in the Geological Collections of the British Museum (Natural History).

	Specimen No. B. 8363 Warminster	Specimen No. B. 93141 Norwich
SiO ₂	79.21	0.30
CaO	11.20	56.06
CO ₂	7.51	43.04
P ₂ O ₅	Trace	Trace
Fe ₂ O ₃	1.30	Trace
	99.22%	99.40%

should have broken down in hydrochloric acid, and this seems to suggest that the SiO₂ was in a colloidal or amorphous state and not cryptocrystalline.¹

The disintegration in dilute hydrochloric acid of these partially silicified rhynchonellid shells was found to vary considerably even in specimens from the same locality and indicated some variation in the silica-content and composition. In every case, however, the matrix infilling the shell was found to be soluble in acetic acid.²

Partial success only was had with the terebratulids and terebratelids in which the shell is punctate and less able to withstand the acid than the fibrous shells of the rhynchonellids. Further experimental work is being carried out with hardening reagents and treatment of the shell before immersion in acid.

At the Geologists' Association Reunion in November 1951, the authors exhibited some silicified brachiopods from the Palaeozoic of North America and Great Britain, from the Lias of Chile and from the Inferior Oolite of Normandy, that had been freed from their calcareous matrix by immersion in dilute hydrochloric acid. More recently, Liassic brachiopods from the South of France were similarly treated and yielded perfectly preserved zeilleriid loops. The substitution of acetic acid for hydrochloric, however, gives better results with such fragile specimens and there is a greater likelihood of the internal brachial skeleton being preserved intact.

TECHNIQUE EMPLOYED

The best results are obtained with large blocks in which the fossils are silicified, but single uncrushed specimens, with no externally adhering matrix, have been freed from infilling matrix and yielded, when immersed in dilute acetic acid, perfect interiors of the two valves.

It was found convenient, in the case of small specimens, to place them on a removable, perforated, acid-resisting platform made of

¹ Much has been written on the subject of colloidal silica and its source in Cretaceous beds, especially in the Aptian and the Lower Chalk, by Hinde (1885), Jukes-Brown and Hill (1889) and by others.

² Immersion of such partially silicified specimens in a buffer acetic acid solution, adjusted to pH between 4 and 6 with 20 per cent ammonium acetate solution, did not dissolve out the matrix as in the case of 15 per cent acetic acid.

perspex or glass and raised a few inches above the base of the container. When immersed in the acid, the sludge tends to drop through the perforations, while the freed silicified specimens remain on the platform instead of being mixed with the sludge, and can readily be removed with less risk of breakage.

The specimens are washed for about six hours in slow-running water, dried on blotting paper and then treated in a dilute solution of some hardening agent for about an hour. A thin solution of polyvinyl acetate emulsion, about the consistency of milk, was found to be best for brachiopod shells. The emulsion should be diluted with distilled water since the use of tap water may result in a thick precipitate of the plastic. After removal from the hardening solution, the specimens should be placed on a sheet of plate-glass smeared with vaseline. This will prevent excess solution adhering to the surface of support. The drying process can be accelerated by placing the specimens on a wire gauze tray in a low-temperature oven.

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THE JURASSIC ROCKS OF THE LINCOLN DISTRICT

By W. David Evans, M.Sc., Ph.D., F.G.S.

[Received 2 February 1951]

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ABSTRACT.—A description is given of the distribution and lithological character of the Jurassic rocks of the Lincoln District. Special mention is made of the variations in the composition of the Northampton Sand and of the Lincolnshire Limestone, and an attempt is made to show that the ironstone facies of the former have been developed in an isolated sand-girt basin. The structure of the area has also been described and attention is drawn to a possible relationship between the faults in the area and discontinuities in the Palaeozoic floor.

1. INTRODUCTION

THE area mapped and described forms a narrow belt of country extending $3\frac{1}{2}$ miles to the north and $12\frac{3}{4}$ miles to the south of the City of Lincoln. Its western margin is marked by the crop of the Lias clays and Northampton Sand along the Lincoln Cliff. To the east, the area extends over the crop of the Great Oolite Series. In all, about 85 square miles have been surveyed on the six-inch scale. Initially this investigation was carried out for the Geological Survey as part of the wartime survey of the bedded Jurassic ironstones. Following the discovery of an inlier of Northampton Ironstone and Upper Lias Clays, the work was extended to establish other such inliers and structural features of the area. At the outset, I wish to record my indebtedness to the Director of the Geological Survey for permission to publish this work.

Prior to this survey, the only published map incorporating the area was the one-inch to a mile Old Series Sheet 83 of the Geological Survey. This was published in 1886 with an accompanying memoir under the joint authorship of W. H. E. Ussher, A. J. Jukes-Browne and Aubrey Strahan. Subsequently, repeated references have been made to the geology and glaciology of this area and the Geological

Survey map has been reproduced without revision in several geographical publications (see list of references p. 334).

In 1918, Trueman established, for the first time in this area, the zonal divisions of the Middle and Upper Lias, and demonstrated the unconformity which exists at the base of the Inferior Oolite. Kent and Baker (1937) recorded ammonites from the Lincolnshire Limestone and later Kent (1941) published a valuable lithological correlation of this formation throughout Lincolnshire. On the occasion of the field meeting of the Geologists' Association at Lincoln, Richardson (1940) described in outline the stratigraphy of this area.

2. THE STRATIGRAPHICAL SUCCESSION

Within the area to be described, the following formations have been surveyed on the six-inch to a mile scale. The glacial and alluvial deposits have been omitted from the map and the description of the area, but the nature of these deposits is indicated in outline in the succeeding tabulated stratigraphical succession:

THE JURASSIC SUCCESSION IN THE LINCOLNSHIRE DISTRICT

							Thicknesses in feet		
RECENT DEPOSITS	{	6. Brown sands	0 to 20						
		5. Black peaty clays	5 to 10						
		4. Brown sandy clays with quartzite, limestone and ironstone pebbles	3 to 8						
		3. Black peaty and sandy clays	5 to 10						
		2. Brown sandy clays	0 to 5						
		1. Yellow and brown sands and sandy clays with quartzite gravels	over 15						
GLACIAL DEPOSITS	{	4. Chalky boulder clay	over 12						
		3. Coarse quartzite gravels	5 to 15						
		2. Blue clay with some flints and chalk... ..	15 to 25						
		1. Yellow pebbly sands and coarse gravels	over 5						
JURASSIC:—									
Cornbrash	...	...	...	...	...	...	3 to 4		
Great Oolite Series	{	3. Great Oolite Clay	20 to 23						
		2. Great Oolite Limestone	19 to 24						
		1. Upper Estuarine Series	23 to 28						
(Unconformity)									
Inferior Oolite Series	{	Lincolnshire Limestone	Upper	Hibaldstow Beds ...	35 to 50				
				<i>A. crossi</i> Beds ...	10 to 12				
		Lower	Kirton Cementstones	8 to 12					
			Blue and Silver Beds	10 to 12					
		(Unconformity)							
		Lower Estuarine Series	...	...	...	...	0 to 4		
(Unconformity)									
Northampton Sand	...		...	...	...	8 to 12			
(Unconformity)									
Lias	Upper Lias	...	...	...	...	...	85 to 90		

3. THE JURASSIC ROCKS

(a) **Lias.** The Liassic deposits have not been mapped in detail, so that the distribution of the Lower, Middle and Upper divisions,

which occur in this district, is not shown in the map on Plate 11. Predominantly composed of clays and shales with thin impersistent beds of impure limestones and nodular calcareous ironstones, these formations crop out over the low ground to the west, and also form part of the scarp-slope of the Lincoln Cliff. In addition to the main outcrop, hitherto unrecorded inliers of Upper Lias clays are exposed in the valleys to the north of Lincoln, and in those to the south-east in the neighbourhood of Branston and Waneham Bridge (see Plate 11). Their occurrence is due, not so much to the development of valley-bulges (see Hollingworth, S. E., *et al.*, 1944), as to the erosion of valleys into the Upper Lias through almost horizontally disposed Inferior Oolite strata.

Sections of the Lower, Middle and Upper divisions of the Lias are exposed in brick pits situated along the Lincoln Cliff. The majority of these are now disused and either grassed over or flooded. In the Bracebridge Brick Pits, situated $2\frac{1}{2}$ miles SW. of Lincoln Cathedral, good exposures still exist (particularly in the one at present in work) of the clays and shales of the Middle and Upper Lias, and also of the junction of the latter with the overlying Northampton Sand. The ammonite zones established by Trueman (1918) are all exposed in these sections. His original material has recently been arranged in zonal order in the collections of the University of Nottingham where his work was originally carried out.

Throughout the greater part of this area, no well-defined development of limestones or ironstone marks the horizon of the Marlstone Rock Bed. In the extreme south, such shelly calcareous ironstones and limestones reappear and attain to workable thicknesses and quality as an ironstone in the neighbourhood of Caythorpe, three miles south of Leadenham. At Waddington, the Marlstone Rock Bed is probably represented by a thin limestone which crops out on the old brick pits situated to the west of the village. Similar deposits are also exposed in the escarpment below Coleby and in the railway cuttings situated to the west of Boothby Graffoe. In the vicinity of Lincoln, this horizon is probably represented in the brick-pit sections by the shelly limestones and shales of the *pseudovatum-falciferum* Subzones (see Trueman, A. E., 1918, p. 104).

Along the south side of the Lincoln Gap, boreholes for supplying water to cottages, situated due west of Washingborough, proved a disturbed bed of limestone about 6 ft. thick at a depth of 30 ft. It is possible that this limestone also marks the position of the *pseudovatum-falciferum* Subzones which have here been displaced upwards by valley-bulge movements developed within the fault-system of the Lincoln Gap.

The Upper Lias clays and shales vary from 80 to 100 ft. in thickness throughout the area. At Bracebridge, Trueman (1918, p. 111) demonstrated the incompleteness of the *bifrons* Zone by the absence of the *fibulatum* and *braunianum* Subzones. It is likely that the Upper

Lias clays exposed in Branston Brook, due west of Branston Church, belong to the *subcarinata* Subzone of the *bifrons* Zone of the Upper Lias.

The junction of the Upper Lias with the succeeding Northampton Sand (Inferior Oolite) is invariably sharp and is exposed in several pits and roadside sections throughout the area. At several of these localities, and particularly in the air-raid shelter excavations near the Arboretum, Lincoln, or in Bracebridge Brick Pit, this junction is marked by a deposit of rolled and fragmented phosphatic nodules admixed with clay-pellets and ferruginous sand. This was described by Ussher (1888, p. 38) as a 'coprolite bed'. The phosphatic nodules show distinct signs of erosion and are often broken into angular fragments. In addition, they are usually admixed with whisps and lumps of clay obviously derived by erosion from the Upper Lias.

(b) Inferior Oolite

1. NORTHAMPTON SAND

At outcrop, and over considerable areas under cover, this formation is represented either by ferruginous sands and sandstones, or well-bedded oolitic sandy ironstones. From field, borehole and well-section evidence, an attempt has been made to establish the relationship between these two facies, and the results have been plotted in the form of an isopachyte map (Fig. 1). Locally both facies of the Northampton Sand are absent, but when present the ironstone either wedges out sharply or passes rapidly into the sandy facies. In general it may be stated that the sands surround the northern, eastern and southern margins of this restricted but centrally disposed ironstone field. The facies-variation, indicated diagrammatically in Fig. 1, is based upon the assessment of exposures and borehole-sections in terms of the ironstone content. Formations containing not less than 75 per cent of massive and boxstone ironstone are classified as belonging to the 'ironstone facies' and the remainder grouped into the 'sandy facies'.

(a) Ironstone Facies

In its unaltered condition, the ironstone consists of well-bedded deposits of bluish-green sideritic and chamositic sandy mudstones (some of which are crowded with ooliths) interbedded with lenticular limonitic sandstones. Exposures of the unaltered ironstone were examined during this underground survey in parts of the Greetwell Mines, and particularly in those workings situated in Greetwell Hollow. Elsewhere, the ironstone, wherever seen, was entirely oxidised to the limonitic 'boxstone' variety.

At Greetwell Hollow, on the eastern outskirts of Lincoln, the ironstone has been worked extensively by open quarry and underground-mining methods. Excavations in the older parts of the workings have revealed Roman pottery and slags which indicate an

early phase in the development of this site. The field note-books of W. H. Penning (*Records of the Geological Survey*) clearly indicate that underground, as well as opencast, developments by the Mid-Lincolnshire Iron Company, were in full swing by 1878. In the published memoir of the original survey, Messrs. Dalton and Penning (in Ussher, W. H. E., *et al.*, 1888, p. 39) recorded the following observations:

Here 16 feet of ironstone, mostly peroxides, but partly blue- or green-hearted, is quarried into a tramway extending along the floor of a trench, of which one side is the unmoved ore, with a capping of 10 to 12 feet of oolitic rubble. . . . Successive widths of the ore are cleared of the capping, which is carried on planks across the trench, which is moved to the west by the quarrying away of the shelf of ore. Though the ground rises westward, the rise of the beds is for the present so nearly equal, that the capping is not increasing in depth as the work proceeds, whilst further up the hill the ore has been reached by tunnel-mining, and considerable areas have been worked out, the overlying rock allowed to fall in by the removal of the timbering. The lower 2 feet of the ironstone is so crowded with phosphatic nodules as to be worthless for smelting, whilst its hardness has deterred the makers of phosphatic manures from attempting to utilise it as a source of phosphoric acid although by weathering the ferruginous matrix soon breaks up and frees the nodules.

In addition to this factual record of the character of the ore and the methods of mining used, it is evident that even these early workers were struck by the way in which the ironstone deposits were arched on the valley-sides by cambering effects of superficial movements.

In general the ironstone worked throughout Greetwell Hollow averaged 6 to 10 ft. in thickness. The workings were conjointly open-cast and underground. In this way a good average iron-content was maintained in spite of the fact that considerable quantities of comparatively inferior, unweathered, ore were extracted from the bord-and-pillar workings underground. The opencast workings yielded essentially weathered high-grade ironstone at a cost much below that at which it could be mined. Furthermore, overhead costs in the open workings were materially reduced by the disposal of the overlying Lincolnshire Limestone as road-ballast and building stone. During its peak period of working—during World War I—the output from Greetwell, which averaged 3000 tons per week, was absorbed by the furnaces at Scunthorpe, where it was largely consumed as a siliceous blende with the decidedly calcareous Frodingham Ironstone.

To the east of Greetwell Hollow, the ironstone is traversed by a north-south fault-system, which, in effect, lowers the ironstone over 50 ft. to the east. This was one of the factors which brought mining in this direction to a close in 1938. In addition to the excessive degree of 'cross-measure drivage', which would be necessary to reach the downfaulted ironstone, boreholes had shown that the ore-bed was thinning rapidly (see Fig. 1). To the north, the extension of the relatively shallow underground workings was prevented by building-developments and the discouraging results obtained from trial holes

FIG. I.
ISOPACHYTE MAP OF THE
SAND

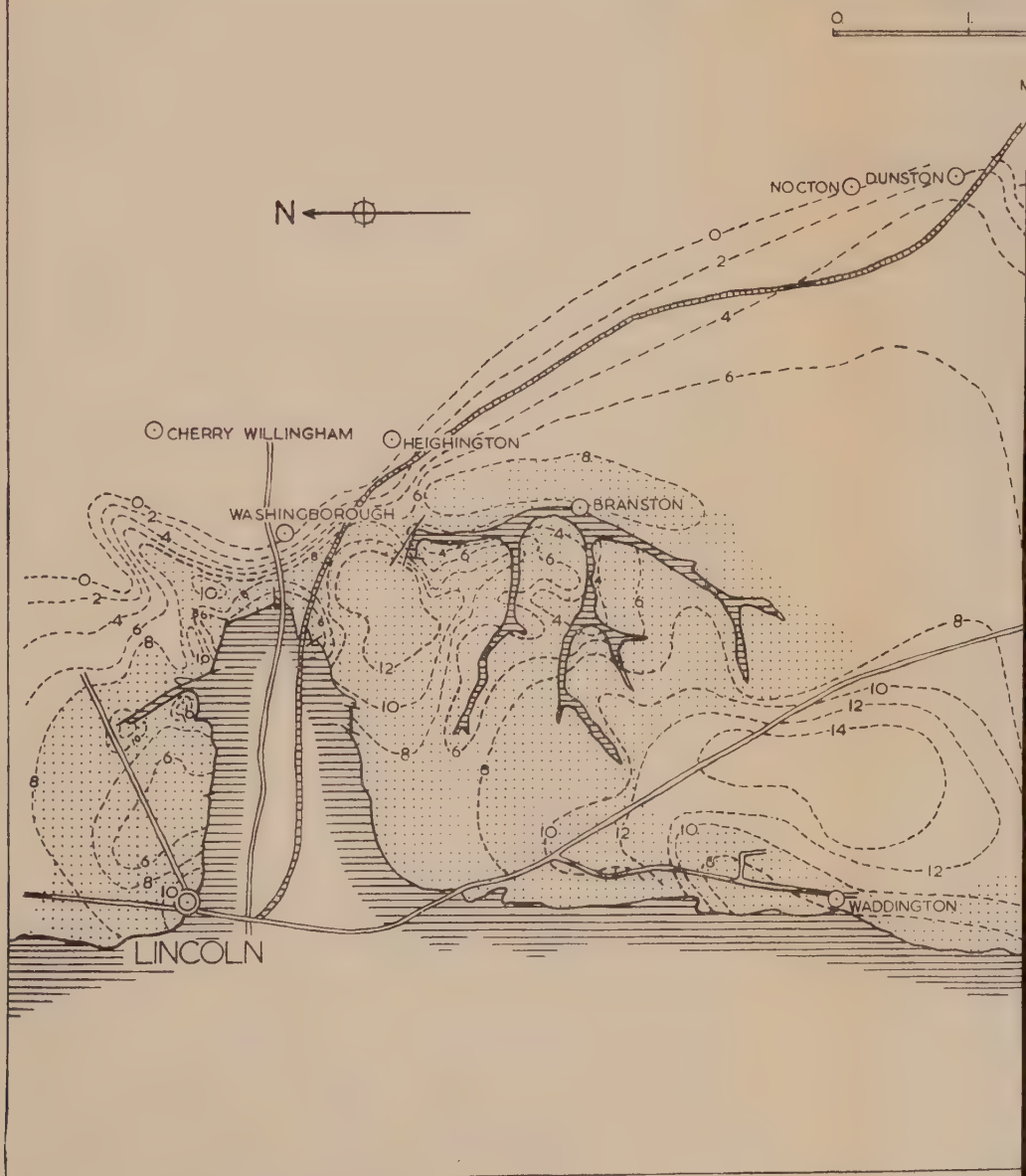


FIG. 1.—Isopachyte Map of the

NORTHAMPTON

2 miles

BRINGHAM

SCOPWICK

BLANKNEY



Sandy facies.

Approximate boundary

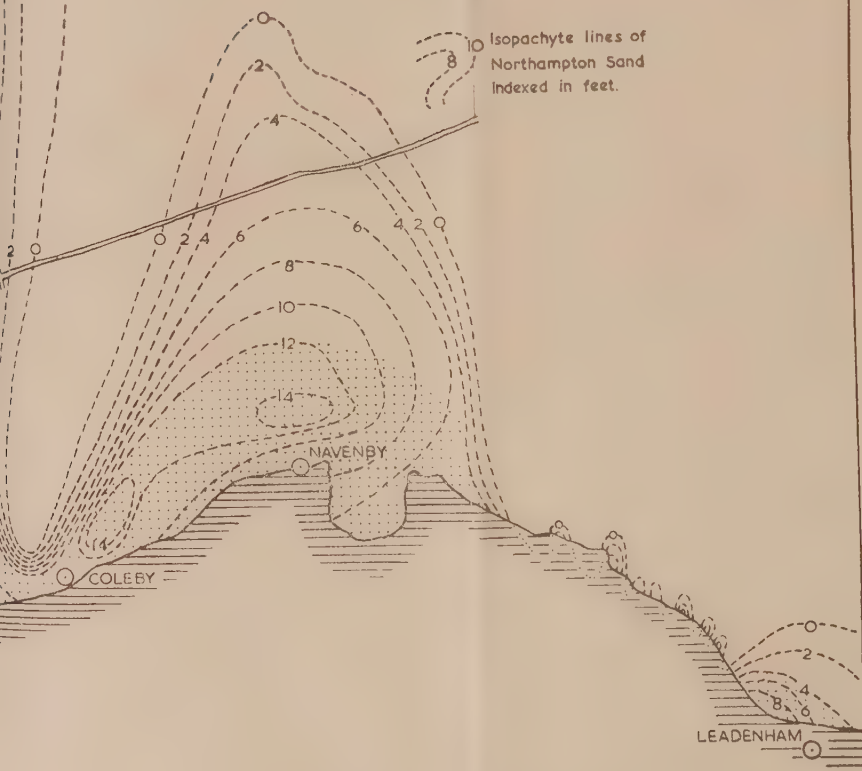
Ironstone facies.

Northampton Sand.



Exposed Lias clays.

Isopachyte lines of Northampton Sand Indexed in feet.



Northampton Sands.

[To face p. 320.]

put down by the Mid-Lincolnshire Ironstone Company which showed that the ironstone was thinning and deteriorating in quality northwards. Examination of the ironstone, which is occasionally exposed along the Lincoln Cliff, supports the view that the Northampton Sand becomes progressively more sandy to the north.

On the south side of the Lincoln Gap, the ironstone facies crops out at several places between Canwick and Washingborough. At the northern entrance to the railway cutting, south-west of Washingborough, is an exposure of some 4 ft. of completely oxidised, sandy-

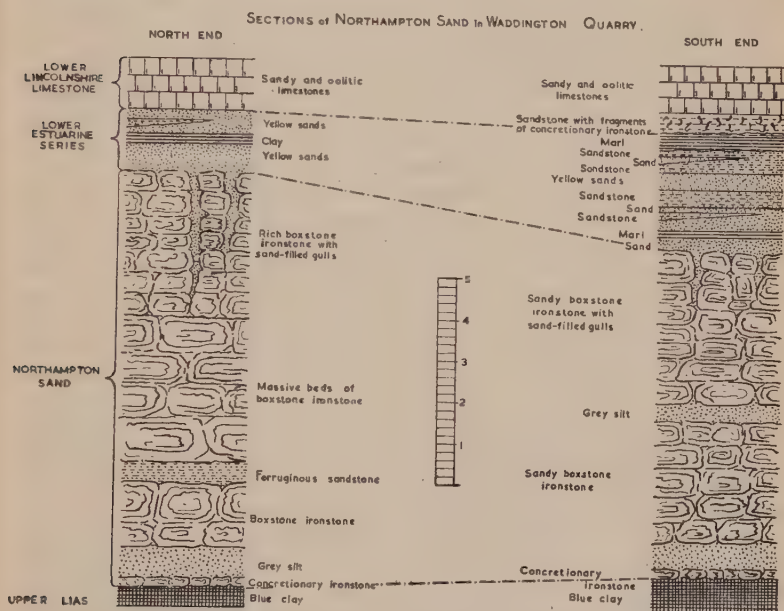


FIG 2.—Sections of Northampton Sand in Waddington Quarry.

boxstone ironstone. Likewise, at Sheepwash Farm, 8 ft. of completely oxidised ironstone was revealed by an excavation made during this survey. Similar thicknesses of ironstone were recorded from nine trial holes put down at widely spaced points over the farm. On analysis the ironstone from these trial holes varied in quality, but averaged 32 per cent iron, 26 per cent silica and 2 per cent lime. Samples of ironstone taken from the floor of the old limestone workings at Canwick also indicated that the iron-content of the Northampton Sand on the south side of the Lincoln Gap had deteriorated and that the silica-content exceeded the average recorded from the 'run-of-mine' ore extracted from Greetwell Hollow.

Exposures of sandy boxstone occur on the roadside at the top of the hill leading to Bracebridge, and its junction with the underlying Upper Lias clays is visible in the adjacent disused brick-pit known as Best's Pit. There, eight feet of oxidised ironstone, with traces of the basal 'coprolite bed', are exposed. Further south, isolated exposures of oxidised ironstone occur along the Lincoln Cliff.

Fully illustrating the variable character of parts of the truly ironstone deposits are the beds exposed at the north and south ends of what is now known as 'Howard's Quarry', which is situated on the north side of Waddington village (see Fig. 2). At the south end of the workings a freshly opened face showed 7 ft. 8 in. of Northampton Sand. When channel-sampled it yielded 19.9 per cent iron (as Fe_2O_3), 53.0 per cent silica, 4.6 per cent lime, 1.3 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$., 9.7 per cent loss on ignition, 0.6 per cent P_2O_5 and 0.1 per cent sulphur. These workings are situated on the site of an old ironstone quarry which, when working in 1874, apparently yielded a much superior quality of ironstone to that now available. On the north side of these old workings the deposit showed a marked improvement in quality. The analysis gave 26.1 per cent iron (as Fe_2O_3), 12.3 per cent silica, 3.9 per cent lime, 0.8 per cent P_2O_5 , 1.4 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$., 9.5 per cent loss on ignition and 0.6 per cent sulphur. The relationship between these two sections (shown in Fig. 2) illustrates the rapid lateral and vertical variations which repeatedly take place in the Northampton Sand as it is traced southwards from Waddington along the Lincoln Cliff as well as eastwards down-dip. Some exposures show 6 to 7 ft. of boxstone ironstone while neighbouring ones, some 50 yards away, may consist of alternations of yellow sand, ferruginous sandstones and some boxstone ironstone. Where the deposit is composed entirely of ironstone, it is usually of superior quality. For example, a channel-sample taken from an exposure of ironstone, $6\frac{1}{2}$ ft. thick at 1400 yards north of Harmston Hall, showed on analysis 54.1 per cent iron (as Fe_2O_3), 20.8 per cent silica, 5.0 per cent alumina, 3.9 per cent lime, 0.8 per cent P_2O_5 , 0.1 per cent sulphur, 1.3 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$. and 13.6 per cent loss on ignition.

A similar increase in the iron-content of the Northampton Sand accounts for the attempt in 1874 to mine the ironstone underground from an adit entering the crop at a point 530 yds. S. 20° E. of Coleby Church. Most of these workings are now overgrown, but records show that an adit was driven 346 yds. E. 43° N. from this point on the crop to link up with an air-shaft, the remains of which can still be traced. At the entrance to the mine, the ironstone yielded on analysis 58.06 per cent iron (as Fe_2O_3), 13.17 per cent silica, 6.10 per cent alumina, 2.94 per cent lime, 0.89 per cent MgO , 0.02 per cent MnO , 0.59 per cent P_2O_5 and 11.86 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$. (Analysis quoted from Dagleish and Howse, 1874, p. 30). Penning's description (in Ussher, W. H. E., *et al.*, 1888, p. 38) of the ironstone exposed at

the mine entrance differed considerably from that recorded in the air shaft by Macdakin (1877, p. 407) and have been recorded here to emphasise the extreme variability of the ironstone in this area.

SECTION AT THE ENTRANCE TO COLEBY MINE (Penning, 1888)

							Ft.	in.
Lower Lincolnshire Limestone	{	Fine grained Oolitic limestone	...	...	...	...	5	0
Northampton Sand	{	Sandy ferruginous limestone, partly converted into ironstone	...	...	...	...	1	6
	{	Sandy clay	...	...	...	...	0	9
	{	Ironstone	...	...	...	...	6	0
Upper Lias	{	Blue Lias clay	...	...	...	...	—	—

AIR SHAFT SECTION AT COLEBY MINE (Macdakin, 1877)

							Ft.	in.
Lincolnshire Limestone	{	Oolitic limestone	...	...	...	...	35	0
	{	Peroxide bed	...	...	...	...	0	8
	{	Clay ironstone	...	...	...	...	0	4
	{	Hard carbonate of iron	...	...	...	...	0	9
	{	Clay parting	...	...	...	...	0	4
Northampton Sand	{	Hard blue carbonate of iron	...	...	...	...	1	4
10 ft.	{	Peroxidised band	...	...	...	...	0	10
	{	Nodules and clay partings	...	...	...	...	0	11
	{	Blue ferruginous sand bed	...	...	...	...	1	1
	{	Ironstone nodules	...	...	...	...	0	6
	{	Clay with nodules	...	...	...	...	3	0
	{	Coprolites and pyrites	...	...	...	...	0	3
Upper Lias	{	Blue Lias Clay	...	...	...	...	—	—

Macdakin also noted, from an inspection of the mine workings, the considerable variations which have taken place in the character of the ironstone in this district and pointed out that the upper beds were siliceous and the lower were argillaceous. 'Some of the richer bands contain as much as 40 per cent of iron which in the more siliceous portions falls to 28 per cent. . . . For 200 yards from the outcrop, the beds are of a deep reddish brown colour; then changing into bluish-grey carbonates' (Macdakin, J. G., 1877, p. 407).

Southwards along the Lincoln Cliff to Navenby the Northampton Sand averages 8 ft. in thickness and persists as a series of beds of boxstone ironstone. Between Wellingore and Leadenham considerable variations occur; here masses of ironstone pass rapidly into interbedded yellow sands, silts and clays.

Further south the ironstone recovers its thickness and workable quality in the disused Leadenham workings. Here the Northampton Sand is in places over 7½ ft. thick, and a channel-sample, taken from the most northerly part of the ironstone exposed in the quarry, showed on analysis 48.9 per cent iron (as Fe₂O₃), 16.3 per cent silica, 3.9 per cent lime, 8.6 per cent alumina, 1.1 per cent P₂O₅, 0.2 per cent sulphur, 1.8 per cent H₂O < 105°C., 17.9 per cent loss on ignition.

The old ironstone-workings and the associated Dove's Limestone

Quarry were reopened during the war, principally for the excavation of the Lincolnshire Limestone overburden. A carefully measured section in the quarry showed the following succession:

		Ft.	in.
Cementstones 18 ft. 8 in.	{ Creamy yellow weathering fine-grained limestones with <i>Nerinea</i> sp., <i>Astarte</i> sp. and <i>Pinna</i> sp. with shelly and oolitic marl and marly limestone ...	18	8
Blue and Silver Beds 9 ft. 4 in.	{ Yellow weathering, fine-grained limestone, often shelly and oolitic ... (sharp junction)	9	4
Lower Estuarine Series 6 ft. 1 in.	{ Brown weathering blue-grey sandstone ...	1	0
	{ Yellow sandy clay ...	1	6
	{ Yellow sands and sandy clays separated by a thin bed of green clay ...	1	10
	{ Brown, laminated, ferruginous, calcareous sandstone ...	0	9
	{ Banded, greenish-blue and brown clays ... (uneven junction)	1	0
	{ Brown, sandy ironstone with boxstone structure...	2	0
Northampton Sand 7 ft. 11 in.	{ Blue-green clays with plant fragments ...	0	4
	{ Sandy ironstone with boxstone structure...	1	10
	{ Greyish brown, sandy and oolitic ironstone ...	1	2
	{ Sandy clay-ironstone with some boxstone structure ...	0	7
	{ Soft, sandy clay-ironstone (completely oxidised)...	1	6
	{ Base of ironstone (proved by auger) at ...	0	6

On analysis a channel-sample through 7 ft. 6 in. of ironstone, taken from the northernmost exposure of Northampton Sand, yielded 48.9 per cent iron (as Fe_2O_3), 16.3 per cent SiO_2 , 8.6 per cent Al_2O_3 , 3.9 per cent CaO , 1.1 per cent P_2O_5 , 0.2 per cent S, 17.9 per cent loss on ignition and 1.8 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$. The few inches of plant-bearing clay near the top of the Northampton Sand appears to represent an early but temporary incoming of estuarine conditions at this locality. Similar conditions are expressed in the good roadside exposures on the hill nearby. Although not yet mapped in detail, it is evident that, between Leadenham and Ancaster, the Northampton Sand is very variable in composition and, in places, appears to be altogether absent.

Information from boreholes suggests the entire absence of Northampton Sand and Lower Estuarine Series from the ground to the west of Nettleham. This correlates with the evidence afforded by boreholes put down to the east of the Greetwell workings, wherein no trace of Northampton Sand was recorded (see Fig. 1).

In the valleys which extend northwards, westwards and southwards from the village of Branston, an average thickness of six feet of boxstone ironstone is exposed in this extensive inlier. A channel-sample taken from an excavation 450 yds. E. 30° S. of Ashfield House, Branston, which revealed 7 ft. 3 in. of boxstone ironstone, yielded on analysis 36.6 per cent iron (as Fe_2O_3), 39.7 per cent silica, 1.8 per cent lime, 7.3 per cent alumina, 1.2 per cent P_2O_5 , 0.1 per cent sulphur, 1.9 per cent $\text{H}_2\text{O} < 105^\circ\text{C}$. and 10.6 per cent loss on

ignition. Similar high-silica ironstones were exposed in trial-holes put down at Ackroyds Quarry, near Cliff Farm, north of Branston. Trial-holes, piercing the Lincolnshire Limestone on the western side of the valley from Cliff Farm, proved equally disappointing as the silica-content in the ironstone always exceeded 20.0 per cent. From field evidence, it seems probable that the best quality ironstone in this Branston field is situated in the valley alongside the Branston-Canwick road. In the valley running southwards from Branston, no specific evidence was obtainable of the quality of the ironstone. However, a section of boxstone ironstone, 7 ft. 3 in. thick, inspected in a well at Mere Hall, south-west of Branston, appeared from visual observation to be quite rich in iron and not excessively sandy. In the valley extending westwards from Waneham Bridge, the ironstone, wherever it exists, appears to be completely oxidised and although its presence and character have been explored solely by hand-auger holes, it is evident that it varies greatly in lithology and will be largely unworkable.

(b) *Sandy Facies*

In addition to the augered sections made along the Lincoln Cliff between Welbourn and Leadenham, these deposits have been examined in well-sections and from borehole samples. The most complete section of this facies of the Northampton Sand was revealed by the recent borehole put down at Waneham Bridge, and by three made in the vicinity of Temple Grange, Navenby. These sections serve to illustrate the nature of this so-called 'sandy facies' of the Northampton Sand which exists in the southern and eastern parts of the area. Briefly, the results obtained were as follows:

				Thickness in feet			
				Waneham Bridge	Temple Grange		
Lincolnshire Limestone	...	...		68½	85½	51	77
Lower Estuarine Series	...	...		—	—	—	—
Northampton Sand	{ Ironstone	...	...	1½	—	—	—
	{ Sands	...	...	3	3	—	9
	{ Shale	...	...	1½	—	—	—
	{ Sand and Sandstone			4	2	3	1½

For several miles to the south of Leadenham no extensive deposits of ironstone appear to exist. Likewise, northwards from Lincoln, the boxstone-ironstone facies is progressively replaced by the sandy facies, which consists of yellow sands and sandstones and grey silts with occasional thin beds of clay. In places outside the area mapped, the formation is absent, as, for example, in the boreholes for water supplies put down at Caenby Corner. On the other hand, boreholes put down near the neighbouring village of Glentham proved 25 ft. of silts and yellow sands (probably Lower Estuarine Series) overlying 18 ft. of yellow sandstones belonging to the Northampton Sand. In general it may be assumed that such variations in the thickness and nature of the

Northampton Sand is typical of all areas outside those occupied by the truly ironstone facies. Furthermore, their relationship suggests the deposition of sandy sediments around the irregular margin of an epicontinental cuvette wherein tidal currents played a pronounced part in channelling the underlying Upper Lias clays and in building up sand banks and sandy mud flats. On the other hand the well-bedded nature of the ironstone facies indicates that they were developed in the deeper parts of the basin. This conception is strongly supported by the isopachyte map (Fig. 1) of the Northampton Sand.

This interpretation of the facies-relationships of the Northampton Sand in this area, is a view which also derives support from the works of Skerl (1927) and Taylor (1949). Taylor states that, 'it seems almost certain, however, that material has been derived from both sides of the basin . . . and crystalline rocks of Charnwood Forest and the east Midlands were probably undergoing erosion at the time of deposition of the Northampton Sand' (Taylor, J. H., 1949, pp. 79-80). The marked thinning of the Northampton Sand eastwards and the apparently restricted distribution of these deposits support Taylor's view of a western as well as the south-eastern source of detritus postulated by Skerl.

2. LOWER ESTUARINE SERIES

Throughout the area this formation is extremely variable in character and thickness. Where preserved at outcrop, the Lower Estuarine Series usually consists of laminated grey and mauve-tinted silts and clays with thin beds of pale yellow sands, impersistent sandstones and black carbonaceous clays which often contain plant-remains. Frequently these deposits are absent and the Lincolnshire Limestone rests directly on uneven surfaces of the Northampton Sand, and, in some places, the junction shows unmistakable signs of erosion.

In the Greetwell ironstone-workings, the Lower Estuarine Series is represented by impersistent lense-shaped developments of greenish and black, laminated clays and silts. Nowhere are these deposits greater than 3 ft. in thickness in the area mapped, but farther north, as at Glenham, they may locally be 15 ft. thick.

Along the Lincoln Cliff, southwards from Lincoln, the Lower Estuarine Series is never more than 4 ft. thick and is often absent. Where preserved, it consists of an extremely variable series of laminated clays, silts and sandstones such as those exposed in the old ironstone-workings at Waddington (Fig. 2). In the extreme south of the area mapped, these estuarine deposits tend to increase in thickness, as shown by the sections in the old ironstone pits at Leadenham (see Fig. 3). On the other hand, in this locality, they are often absent as was shown by the boreholes put down for water at Temple Grange (see Fig. 3).

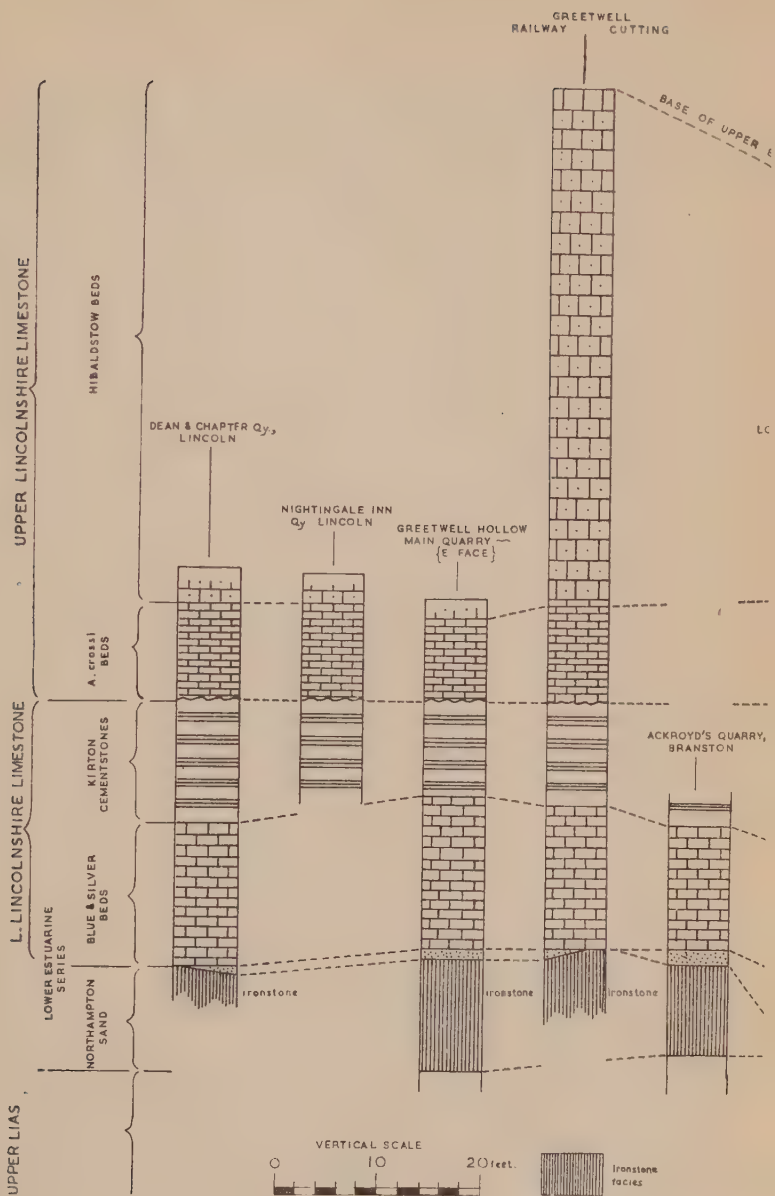
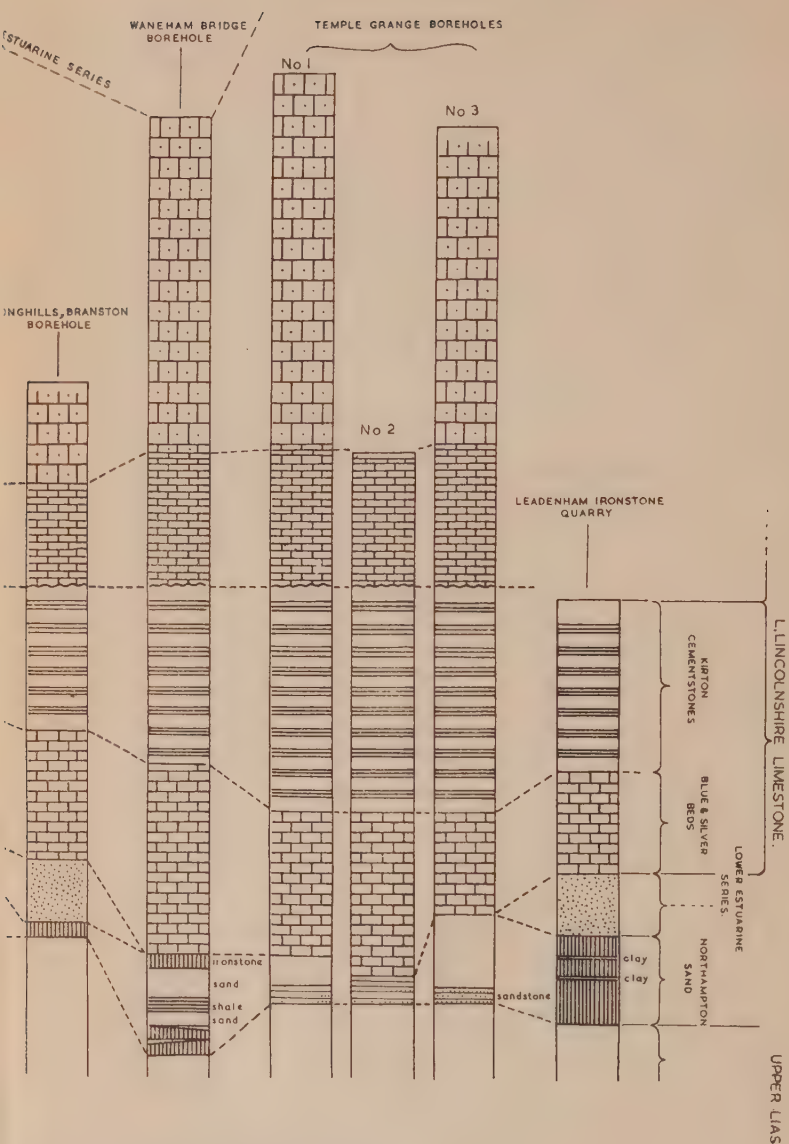


FIG. 3.—Comparative sections of the



Jurassic Rocks in the Lincoln District.

3. LINCOLNSHIRE LIMESTONE

Throughout the area mapped the Lincolnshire Limestone is divisible into several persistent lithological groups. These are outlined on pp. 327-30 and illustrated by vertical sections in Fig. 3, and by the geological map of the area (Plate 11). The mapping of these formations has revealed the geological structure of the area as well as the nature and thickness of the cover over areas of potential reserves of ironstone.

(a) *Lower Lincolnshire Limestone*

(i) *Blue and Silver Beds*

These include the formations described by Richardson (1940, p. 249) separately as 'Blue Beds' and 'Silver Beds'. The detailed mapping of the area made it evident that these two formations represented facies-variations of the basal beds of the Lincolnshire Limestone, and that only locally is it possible to recognise an upper formation of 'Silver Beds' and a lower one of 'Blue Beds'. For this reason, the terms used by Richardson have been blended to cover the lithological nature of the basal beds of the Lower Lincolnshire Limestone throughout this area. As would be expected, the formation is variable in thickness—a feature illustrated by Fig. 3.

The 'Blue Bed'-facies consists of brown-weathering, blue-hearted, ferruginous sandy limestones. The 'Silver Bed'-type is a good 'free-stone' which has been used extensively as a building stone, particularly in the construction of Lincoln Cathedral. In its typical form, it is a pale-weathering even-grained oolite. Nowadays, it is almost exclusively quarried in the Dean-and-Chapter Pit, which is situated on the northern outskirts of the city. Occasionally, beds of this free-stone also occur in the extensive Greetwell Quarries and ironstone-workings to the east of Lincoln.

While the 'Blue Bed' rock-type is usually developed at the base of the Lower Lincolnshire Limestone, it may also be found at any level among shelly, oolitic limestones or iron-stained calcareous sandstones of this formation. Fragments of limonitic boxstone ironstone sometimes occur in the more sandy basal facies of the Blue and Silver Beds. These, it is considered, were derived by erosion from the underlying consolidated, and probably already oxidised, Northampton Sand ironstone.

The junction between the Blue and Silver Beds and the underlying formations, is invariably well-defined and uneven, with clear signs of the pre-erosion of the latter. When resting unconformably upon the ironstone-facies of the Northampton Sand, broken fragments of completely oxidised boxstone usually occur embedded in the creamy-white weathered matrix of the limestones. In addition to this, the basal limestones are usually characterised by segregations of brown-stained ooliths or fragmented limonitic ooliths. Such basal beds are exposed at several places in the Greetwell workings throughout

which the limestone usually rests directly on the uneven surface of the ironstone. Similar relations exist in several exposures along the Lincoln Cliff. For example, in the roadside sections at Harmston and Boothby Graffoe, these basal limestones contain considerable quantities of completely limonitised ironstone which were presumably derived by erosion from the consolidated and oxidised Northampton Sand.

Where silts and clays of the Lower Estuarine Series intervene between the Northampton Sand and the Lincolnshire Limestone, the basal beds of the latter formation often consist of argillaceous and somewhat sandy limestones characterised by scattered segregations of brown-stained and eroded calcite-ooliths. Typical examples are afforded by the roadside-section opposite the Tempest Arms, Coleby, and those in Ackroyd's Quarry, north of Branston village.

In the Greetwell workings, as well as in the railway-cutting at Washingborough, the Blue and Silver Beds are occasionally shelly. From these *Gervillia acuta* J. Sow., *Ceratomya bajociana* d'Orb. and *Pinna cuneata* Phill. have been obtained in considerable numbers. In Ackroyd's Quarry, near Branston, and in the Branston Hall Quarry situated about $\frac{3}{4}$ mile to the west-south-west of the village, certain of these beds are also very fossiliferous. In Dove's Quarry, Leadenham, the Blue and Silver Beds yielded numerous specimens *Nerineae* spp., *Lucina bellona* d'Orb. and *Gervillea acuta* J. Sow.

(ii) Kirton Cementstones

This is a well-defined series composed of limestone beds, 6 to 10 in. thick, alternating with calcareous marls and shales of equivalent thicknesses. The limestones are not usually fossiliferous, but occasionally shelly varieties occur bearing *Pholadomya* spp., *Pinna* cf. *cuneata* and a distinctive, massive-beaked, sub-sphaeroidal, terabratulid (probably a new species) which appears to be restricted to this formation. This was first recognised by Kent (1940, p. 50).

The Kirton Cementstones form a well-defined, 'mappable' formation extending throughout the area. They vary slightly in thickness and in places rest non-sequentially upon the Blue and Silver Beds. Over the central part of the area, the formation maintains an average of 8 ft. in thickness (see Fig. 3), but northwards from Lincoln, it thickens gradually to about 17 ft. Beyond the area here described, it increases in thickness at the expense of the Blue and Silver Beds until it comprises nearly the whole of the Lower Lincolnshire Limestone.

The Kirton Cementstones are fully exposed in many parts of the Greetwell Hollow opencast ironstone-workings. In the easternmost of these, where the ironstone has been almost completely extracted underground by bord-and-pillar methods, collapse had taken place. As a result, collapse-folds of about 2 ft. in amplitude have been

developed in these alternating deposits of limestone and shale which have not been markedly dislocated by compensation-fractures.

In the railway-cutting at Washingborough, the Kirton Cementstones vary from 5 to 8 ft. in thickness. Similar thicknesses occur in the quarries of the Branston district. Farther south, as at Waneham Bridge, this formation increases in thickness with the replacement of the marls and shales by massive beds of limestone.

(b) *Upper Lincolnshire Limestone*

(i) *A. crossi Beds*

This formation, which is about 10 to 12 ft. thick, has been chosen to mark the base of the Upper Lincolnshire Limestone of this area. Almost everywhere it maintains a level of some 25 to 28 ft. above the Northampton Sand, and, wherever exposed, rests on an eroded surface of Kirton Cementstones.

The *A. crossi* Beds consist of pale-blue-grey oolitic and fine-grained, thinly-bedded limestones usually containing abundant specimens of the spinose rhynchonellid *Acanthothyris crossi* (Walker). Occasionally, as in the small quarry near Stonepit Cottages, 950 yds. south of Washingborough Church, these limestones vary laterally into reef-knoll limestones surrounded by calcareous laminated marls. At this locality the basal beds are typically blue limestones with abundant *Acanthothyris crossi*, but grade upwards into knolls of fine-grained limestones which are sometimes coralliferous or shelly.

The *A. crossi* Beds are typically exposed in the vicinity of Lincoln at the Dean-and-Chapter Pit, on the east side of Ermine Street; along the Wragby Road in quarries near the Nightingale Inn; in the quarries behind the Bowling Tree Inn, and in the easternmost iron-stone-workings of Greetwell Hollow. South of the Lincoln Gap they are exposed in the railway-cutting at Washingborough and in many other small quarries and natural exposures. A particularly fossiliferous locality exists in Green Man Wood due east of Boothby Graffoe.

(ii) *Hibaldstow Beds* ($\equiv$ *Ancaster Beds*)

These follow the *A. crossi* Beds in a slightly non-sequential fashion. They consist of an extremely variable series mainly composed of massive, coarsely oolitic and pisolitic limestones associated with relatively thin beds of fine-grained limestone. In all, the Hibaldstow Beds amount to some 40 to 50 ft. in thickness.

Owing to their variable lithological character, the Hibaldstow Beds in this area have not been quarried for 'freestone' to the same extent as those in the Ancaster district to the south. Consequently, exposures are limited to small disused quarries and sections exposed in the railway-cuttings at Greetwell and Washingborough. Fortunately, during this survey, a complete, unweathered section of the Hibaldstow Beds was revealed by the large cores extracted from a

boring put down at Waneham Bridge, near Nocton, to supplement existing water supplies at this pumping station.

BOREHOLE SECTION AT WANEHAM BRIDGE

							Thickness	
							Ft.	in.
GREAT OOLITIC LIMESTONE	...	...	...	...	...	...	23	6
UPPER ESTUARINE SERIES	...	...	...	...	...	...	10	0
(Unconformity)								
LINCOLNSHIRE LIMESTONE								
Hibaldstow Beds								
Creamy-weathering blue-grey limestone	...	...	...	...	...	...	0	9
Pale grey, fine-grained limestone with scattered, weathered, ooliths	...	...	...	...	...	...	2	0
Pale blue-grey, coarse oolite with lenses of brecciated, dark, oolitic limestone	...	...	...	...	...	...	1	2
Soft, dark-grey, oolitic limestone	...	...	...	...	...	...	0	6
Soft, grey, shelly oolite with irregular patches of brecciated, dark, oolitic shelly limestone	...	...	...	...	...	...	1	2
Pale, blue-grey, fine-grained limestone with scattered patches of weathered ooliths	...	...	...	...	...	...	1	0
Pale blue, oolitic limestone	...	...	...	...	...	...	1	6
Dark grey, shelly, argillaceous limestone, occasionally oolitic	...	...	...	...	...	...	0	3
Blue-grey, compact, shelly limestone grading down into a pisolitic limestone	...	...	...	...	...	...	1	6
Dark grey, shelly, laminated argillaceous limestone	...	...	...	...	...	...	0	9
Blue-grey, coarse oolite	...	...	...	...	...	...	0	9
Soft, fine-grained, blue-grey, limestone	...	...	...	...	...	...	0	7
Massive, blue-grey, pisolitic limestone	...	...	...	...	...	...	3	0
Blue-grey, oolitic limestone with streaks of argillaceous limestone, coralliferous at the top	...	...	...	...	...	...	6	0
Dark grey, argillaceous limestone, sometimes shelly	...	...	...	...	...	...	2	0
Fine-grained, pale grey, argillaceous limestone	...	...	...	...	...	...	3	6
Blue-grey, even-grained, oolitic limestone	...	...	...	...	...	...	1	0
Massive, blue-grey, pisolitic limestones	...	...	...	...	...	...	7	4
(Non-sequence)								
A. <i>crossi</i> Beds	...	...	...	...	...	...	13	0
(Non-sequence)								
Kirton Cementstones	...	...	...	...	...	...	17	3
Blue and Silver Beds	...	...	...	...	...	...	18	6
(Unconformity)								
LOWER ESTUARINE SERIES								(absent)
NORTHAMPTON SAND (see page 00)	...	...	...	...	...	...	10	0
(Unconformity)								
UPPER LIAS	...	...	...	...	...	proved to	10	0

(c) Great Oolite

1. UPPER ESTUARINE SERIES

The junction between the Hibaldstow Beds and the succeeding Upper Estuarine Series is occasionally exposed in this area. In the Greetwell railway cutting it is marked by an angular unconformity and by a bed of ironstone which has been referred to as the 'Ironstone Junction Bed' (Richardson, L., 1940). Its contact with the underlying limestones usually shows distinct signs of erosion. At this locality, the ironstone passes laterally into a rubbly clay-bound limestone-conglomerate. Likewise, the Ironstone Junction Bed is exposed in a

disused quarry 700 yds. ESE. of Washingborough Church, and also in the railway cutting to the south of the village. The ironstone was also recorded at the base of the Upper Estuarine Series in the recent Waneham Bridge borehole.

The Upper Estuarine Series consists of a variable series of yellow sands, mauve silts and vari-coloured clays which often contain abundant plant-remains. Over the greater part of the area, the character of this series was largely established by closely-spaced auger-holes since it is rarely exposed, being usually in faulted relationship with the Lincolnshire Limestone or the Great Oolite Limestone. The best section of the Upper Estuarine Series in this district occurs in the Greetwell railway-cutting where it is down-faulted against *A. crossi* Beds and Hibaldstow Beds. Here, it is over 25 ft. thick and consists of yellow sands, pale mauve and green silts, green and brown clays and occasional impersistent bands of shelly (principally *Ostrea hebredica* Forbes) argillaceous limestones at different levels, but principally at about 15 ft. above the base of the formation. From beds of carbonaceous shale, 18 ft. above the base of the formation, a few specimens of *Lingula kestevenensis* Muir-Wood were obtained.

2. GREAT OOLITIC LIMESTONE

This formation is represented throughout the area by rusty-weathering, irregularly-bedded, shelly limestones, containing *Kallirhynchia sharpi* Muir-Wood, thinly interbedded with calcareous marl. The whole series varies from 19 to 24 ft. in thickness.

Exposures of the Great Oolite Series are not abundant. They are principally to be found in the deep ditches traversing Bunker's Hill, to the east of Lincoln; or in the Greetwell railway-cutting, where these limestones are faulted against the Upper Estuarine Series. The full thickness of these beds was also proved in the boreholes at Waneham Bridge near Nocton (see p. 330).

3. GREAT OOLITE CLAY

This formation consists of some 25 ft. of blue-brown and grey clays with occasional impersistent bands of thin nodular *Ostrea*-limestones. Exposures are few and it has only been possible to establish the existence and character of this formation from hand auger-hole and borehole records. A few rhynchonellids (e.g. '*Rhynchonella concinna*') were obtained from ditch-sections in the Bunker's Hill district.

(d) Cornbrash

Within the area surveyed, small outliers of Cornbrash, consisting of blue shelly limestone, occur above the Great Oolite Clay on the high ground to the east of Greetwell Hollow. Farther east, these form a more continuous crop and have yielded *Lopha marshii* J. Sow. and *Ostrea undosa* Phillips. As far as can be judged, the Cornbrash is

never more than 4 ft. thick but appears to be particularly persistent throughout the area to the east of the ground here described.

4. TECTONIC STRUCTURE

The published maps of the area (Old Series, Sheet 83, Geol. Surv. 1888) indicate a few small faults disturbing the otherwise uniform eastward dip of the Jurassic rocks. Augering and detailed mapping have shown that, whereas the main crop of the Lincolnshire Limestone is composed of nearly horizontal beds, the ground in the east is shattered by north-south step-faults which attain an aggregate downthrow of some 50 ft. to the east. In addition, the ground occupied by the City of Lincoln is markedly block-faulted, but on the opposite south side of the Lincoln Gap the rocks are relatively undisturbed. Furthermore, differences in the level of the Northampton Sand on either side of the Lincoln Gap suggests that this waterway has been developed along an east-west fault-system, which has been modified by subsequent superficial movements.

The nearly horizontal disposition of the rocks of the Inferior Oolite, extending southwards from the Gap, has led, by river erosion, to the formation of fairly extensive inliers of Northampton Sand and Upper Lias clays. This has resulted in an eastward outlet of underground waters from what would otherwise have been an excellent storage area. Consequently, despite the otherwise ideal nature of the limestones and ironstone as major aquifers, little water is obtained from wells sunk into the crop of the Lincolnshire Limestone. On the other hand, where the Lincolnshire Limestone is down-faulted in the east and where this permeable formation maintains contact across the faults, water has accumulated in places under artesian 'head'. This was demonstrated by the recent boreholes at Waneham Bridge, near Nocton. These bore-wells are capable of yielding 540,000 galls. per day with the pumping water-level at only 40 ft. below surface (rest water-level $2\frac{1}{2}$ ft. below surface).

The eastern belt of step-faults is by no means local in its effect. It extends northwards beyond the area mapped through Nettleham, towards Welton and Glentham and thence through the ground between Broughton and Brigg. Farther north, this fault-system disappears beneath the glacial and alluvial deposits of the Ancholme Vale, but it probably extends up to, but not across, the east-west fault-system of the Humber. This northward extension of the fault-system has been deduced from borehole information collected by the author during a hydro-geological survey of North Lincolnshire (Wartime Pamphlet, No. 11, 1941, *Mem. Geol. Surv. Gt. Brit.*).

To the south of Lincoln, this north-south belt of step-faults has been displaced eastwards by the Lincoln Gap fault-system, but continues through Washingborough, Nocton, Dunston, Metherringham and Blankney to Scopwick. Still farther south, the ground has not

yet been mapped in detail, but the evidence available suggests that these dislocations diminish in intensity.

5. SUPERFICIAL STRUCTURES

Along the full length of the Lincoln Cliff, pronounced evidence of landsliding exists. Between Lincoln and Leadenham, movement and dislocation of the strata appears to have been rapid on the steep slopes which characterise the greater part of the escarpment. Elsewhere, cambering replaces landslip and the limestones are open fissured for considerable distances away from the edge of the escarpment. In landslip-areas such fissures are absent—a feature which is probably associated with the narrow zone of ‘plasticised’ Upper Lias clays controlled by the rapid migration of underground waters eastwards towards the clay-floored valleys of Branston and Waneham Bridge. In areas to the north of Lincoln and to the south of Leadenham, wherein the underground waters find no eastward outlets similar to those in the Branston and Waneham Bridge inliers, the usual forms of superficial structures are developed. Sometimes, however, fracture-systems associated with landslips are developed in areas where the sandy facies of the Northampton Sand are affected by outwashing (see Preston, H., 1910).

The development of inliers of Upper Lias clays and Northampton Sand in the valleys of the Branston and Nocton districts, has resulted in the formation of superficial ‘valley-structures’ (see Hollingworth, S. E., *et al.*, 1944). Excellent examples of cambering and gull-formation occur in Ackroyd’s Quarry, north of Branston, as well as in the extensive quarries of Greetwell Hollow.

The Inferior Oolite deposits of Greetwell Hollow are gently cambered southwards into the Lincoln Gap. It appears that this movement has been largely influenced and located by a small north-south tectonic fault (see Plate 11) situated to the east of Greetwell Hollow. Initially, the fault appears to have had an eastward down-throw of not more than two feet, as indicated by its throw on the high ground. When followed south, the throw of the fault increases with the cambering effects until a displacement of some 30 ft. in the relative levels of the Northampton Sand is attained.

In the gap itself, there are several anomalous features which can only be explained by valley-bulging. For example, a series of boreholes, put down along the main road from Lincoln to Washingborough, should have proved at least 90 ft. of Upper Lias clays. Instead, an open-fissured deposit of limestone and shale, 6 ft. thick, was encountered at 30 ft. This yielded water under artesian head rising to nine feet above surface-level. The only feasible correlative of this limestone is the shelly beds and calcareous shales of the Sub-zone *pseudovatum-falciferum* exposed in Bracebridge Brick Pit (see Trueman, A. E., 1918). Such a correlation implies an uplift of some

50 ft. of Lias deposits in this part of the gap, and it is suggested that this adjustment has been mainly effected as a valley-bulge.

Valley-bulges have not been detected in the inliers of Upper Lias clays in the valleys around Branston and Waneham Bridge. On the other hand, cambering of the Lincolnshire Limestone and Northampton Ironstone with attendant gull-formation are frequently developed. Good examples are exposed in Ackroyd's Quarry, near Cliff Farm, Branston. At Waneham Bridge, near Nocton, the construction of wells and boreholes for water supplies revealed dislocations which, from their description, were probably dip-and-fault structures. No infilled gulls were recorded, and this is probably due to the absence in this district of the silts, sands and clays of the Lower Estuarine Series as a source of 'filler' material.

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FORAMINIFERA FROM THE UPPER OXFORD CLAY (JURASSIC) OF WARBOYS, HUNTINGDONSHIRE

By Tom Barnard, Ph.D., D.I.C., F.G.S.

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ABSTRACT.—The present paper consists of systematic descriptions of twenty-two species, of which two are recorded as new, and is the first account of the Foraminifera from the Oxford Clay of England.

A range-chart of the species shows that, while some have a long range, others are restricted and may prove useful for zoning.

1. INTRODUCTION

THE attention of most palaeontologists, collecting from the Upper Oxford Clay of the Warboys Pit, has been held by the excellence of the pyritised ammonites and other macrofauna. The same is largely true of other British localities, and although Foraminifera have been recorded, no description of the microfauna from the Oxford Clay of this country exists.

In 1938 Mr. C. D. Ovey systematically collected seventy-eight samples of clay every few inches throughout the section (P. 34207–34303).¹ I wish to take this opportunity of thanking him for allowing me to describe the fauna extracted from them, and to acknowledge the amount of work involved in carefully collecting these samples.

At about the same time as these collections were being made, W. Dewar and W. E. Graham were making a systematic collection of the ammonites for the Geological Survey. These were subsequently described by Spath (1939), who also determined a zonal sequence for this locality (see Table I, p. 349).

¹ The material was collected with the aid of the Godman Exploration Fund. The figures quoted after the initial letter P. indicate registered numbers in the geological collections of the British Museum (Natural History).

2. A HISTORICAL SURVEY OF WORK ON OXFORD CLAY FORAMINIFERAL FAUNAS

The most important works on Foraminifera from the Oxford Clay are those by Gümbel (1862), Schwager (1865) and Deecke (1886). These deal with faunas from Germany and, although the taxonomy used in these studies is based on work on Lias Foraminifera by Bornemann (1854), the diagrams and descriptions are of fundamental importance to modern workers on Jurassic Foraminifera. Macfadyen (1935) produced an important paper on Jurassic Foraminifera from British Somaliland. Most of the samples described by him were said to belong to the Argovian Stage which is equivalent to the Lower Corallian (*see* Arkell, W. J., 1933 for stage-names and correlation). These Foraminifera, which are preserved in the Sedgwick Museum, Cambridge, on the whole agree closely with those from Warboys. For comparative purposes, the importance of Macfadyen's work cannot be overrated. An attempt was also made by Macfadyen to unravel some of the nomenclatorial difficulties which confront anyone engaged in work on Jurassic Foraminifera.

Three papers have been written on the Foraminifera from the Oxford Clay of England. Crick (1887) briefly mentioned rare Foraminifera from a small quantity of Oxford Clay from Keyston, near Thrapston. From the list five genera were found (*Ammodiscus*, *Lingulina*, *Dentalina*, *Frondicularia* and *Cristellaria*). Apart from the long-range species, *Ammodiscus incertus* d'Orbigny and *Lingulina tenera* Bornemann, no other specific names were given.

Sherborn (1888) wrote a short note on the adherent foraminifer, *Webbina irregularis* (d'Orbigny), a form which is probably synonymous with *Bullopore rostrata* Quenstedt.

Whitaker (1886) describes the fauna from several boreholes in Kent. Foraminifera are recorded from the Oxford Clay of Well No. 2, Chatham Dockyard Extension. Three species of *Cristellaria* are mentioned, but it is hardly possible to draw any definite conclusions from these. Of the forms noted, *Cristellaria crepidula* (Fichtel and Moll) is probably *Planularia protracta* (Bornemann), whereas *Cristellaria rotulata* (Lamarck) is *Lenticulina münsteri* (Roemer).

Little can be gained from a study of these early British papers.

3. STRATIGRAPHICAL DETAILS OF THE SECTION

Spath's (1939) zonal sequence has been here applied. Ovey's collection was largely made from the *lamberti* Zone; *mariae* Subzone, together with some samples from the lower *cordatum* Zone, subzones of *Cardioceras* (*Scarburgiceras*) *martini* and *C. (S.) praecordatum*, mut β . Table I shows the position of the samples in respect of Spath's zones together with the distribution of the Foraminifera found.

4. SYSTEMATIC DESCRIPTIONS¹

The classification used below is that given by Cushman (1940), with slight modifications. As is usual with Jurassic microfaunas, the Foraminifera belong for the most part to one family, the Lagenidae, together with a few other species which on the whole are sporadic and rare but occasionally may become individually abundant.

Family AMMODISCIDAE

Genus: **TOLYPAMMINA** Rhumbler, 1895

Tolypammina sp.

Fig. A, 5 (P. 41186)

Description and Remarks. In the specimens, which consisted of finely arenaceous, long meandering tubes, the initial ends were not preserved. The tube almost doubles its width from end to end, showing a regular increase in growth. The aperture consists of the open end of the tube. Ten specimens were studied.

Family LITUOLIDAE

Genus: **AMMOBACULITES** Cushman, 1910

Ammobaculites sp.

Description. The test is composed of an aggregate of small quartz-grains cemented by a siliceous cement. The shape of the test is extremely variable and generally malformed. It consists of a spiral portion of about six chambers, loosely wound, and followed by a rectilinear uncoiling series of about four chambers.

Remarks. The specimens are rare, and probably occurred in an unsuitable environment. Eight specimens were studied.

Family TEXTULARIIDAE

Genus: **TEXTULARIA** DeFrance, 1824

Textularia sp.

Description and Remarks. The few specimens are badly preserved, and only the alternate arrangement of the chambers can be distinguished. The details of the aperture, composition and original shape of the test are uncertain. Four specimens were studied.

Family PLACOPSILINIDAE

Genus: **PLACOPSILINA** d'Orbigny, 1850

Placopsilina sp.

Description. The adherent test consists of about six hemispherical chambers, arranged in a uniserial, meandrine series. The chambers

¹ All species obtained from the samples are described in the present paper except those of *Ophthalmidium*.

abut against one another with no drawn out connecting necks between them. The chambers increase slowly and regularly in size. In all the specimens studied, neither the initial end nor the final aperture-bearing chambers were preserved. It was therefore impossible to assign these specimens to any species. Four specimens were studied.

Family LAGENIDAE

Genus: **LENTICULINA** Lamarck, 1804

Lenticulina münsteri (Roemer)

Fig. B, 5 (P. 41172)

- 1839. *Robulina münsteri* Roemer, p. 48, pl. 20, fig. 29.
- 1867. *Cristellaria vulgaris* Schwager, p. 661, pl. 34, fig. 19.
- 1884. *Cristellaria sowerbyi* Schwager: Deecke, p. 50, pl. 2, fig. 18.
- ? 1884. *Robulina acutiangulata* Terquem mut. *alta.*: Deecke, p. 50, pl. 2, fig. 17.
- 1886. *Robulina vulgaris* Schwager: Deecke, p. 35, pl. 2, figs. 3, 3a.
- 1935. *Cristellaria münsteri* (Roemer): Macfadyen, p. 13, pl. 1, figs. 10a, b.

Description. The test is a tight coil consisting of about fourteen chambers to each whorl. There is a central boss which is often vitreous and shows earlier whorls beneath. The smooth test has sutures flush with the surface, except on the later slightly uncoiled portion of some specimens where they become constricted. In the early part, the test is often weakly keeled, but later the keel degenerates and finally disappears. Different preservation and infilling of the test often makes the individual specimens appear quite different on superficial examination.

Remarks. There is a strong similarity between these specimens and those occurring in the Lias, which are usually assigned to this species. This is a very common species throughout the succession.

Lenticulina quenstedti (Gümbel)

Fig. A, 6 (P. 41174)

- 1862. *Cristellaria Quenstedti* Gümbel, p. 226, pl. 4, figs. 2a, b.
- 1886. *Robulina princeps* Reuss: Deecke, p. 35, pl. 2, figs. 17, 17a (*non* Reuss).
- 1935. *Cristellaria quenstedti* Gümbel: Macfadyen, p. 14, pl. 1, figs. 13a, b.

Description. Usually the test is a tightly wound spire consisting of eight to ten chambers in each whorl. Sometimes specimens uncoil into a short curvilinear portion of two to four chambers. In cross-section the test is swollen and biconvex. The chief diagnostic character is the occurrence of strongly ribbed sutures which stand out above the general level of the smooth test. A sharp well-developed keel occurring on the periphery of the earlier portion of the test gradually degenerates on the later uncoiled portion. The ribs on the sutures meet at the umbilicus which is bounded by a single rib connecting all the suture-ribs at right-angles.

Remarks. A considerable amount of variation occurs in size, shape and uncoiling of the test. This is a very common species throughout the succession.

***Lenticulina flaccida* (Schwager)**

Fig. B, 7 (P. 41183)

- 1865. *Marginulina flaccida* Schwager, p. 116, pl. 4, fig. 27.
- 1865. *Marginulina resupinata* Schwager, p. 117, pl. 4, fig. 28.
- 1865. *Marginulina megalcephala* Schwager, p. 117, pl. 4, fig. 34.
- 1865. *Cristellaria cornucopiae* Schwager, p. 121, pl. 5, fig. 7.
- 1865. *Cristellaria suprajurassica* Schwager, p. 130, pl. 6, figs. 11, 12.
- 1867. *Marginulina inconstans* Schwager, p. 5, pl. 1, fig. 15.
- 1884. *Marginulina inconstans* Schwager: Deecke, p. 36, pl. 2, fig. 4, 4a.

Description. The test consists of an initial portion of about five chambers coiled into a small loose spire, followed by an uncoiling, curvilinear portion of approximately six chambers. The slightly compressed test is biconvex in cross-section. On the initial end of the smooth test, the sutures are flush with the surface but, on later formed chambers, they tend to become sunken. The final chamber is often swollen and has a radiate aperture on a short, but well-developed, apertural neck.

The chambers on the curvilinear portion of the test tend to decrease slowly in width. The sutures are markedly oblique; consequently the chambers have a tendency to overlap into the spiral portion. Fifty specimens were studied.

Genus: **NEOFLABELLINA** Bartenstein, 1948

***Neoflabellina deslongchampsii* (Terquem)**

Fig. B, 1 (P. 41187)

- 1863. *Flabellina Deslongchampsii* Terquem, p. 216, pl. 10, fig. 13.

Description. The parallel-sided test is compressed and consists of seven chambers. Apart from the sutures being slightly raised, the test is smooth. Three triangular chambers overlap each other and reach the globular proloculum. A series of chevron-shaped chambers, which gradually increase in size, comprise the remainder of the test. A slit-like aperture occurs at the end of an apertural neck.

The species were only found at 12 ft. 8 in. below Stone Band A. Ten specimens were studied.

Genus: **FRONDICULARIA** Defrance, 1826

***Frondicularia franconica* Gumbel**

Fig. A, 1 (P. 41177)

- 1862. *Frondicularia franconica* Gumbel, p. 219, pl. 3, figs. 13a, b, c.
- 1865. *Frondicularia lingulaeformis* Schwager, p. 113, pl. 4, fig. 11.
- 1865. *Lingulina ovalis* Schwager, p. 116, pl. 4, figs. 21 to 24.
- 1884. *Frondicularia* cf. *lingulaeformis* Schwager: Deecke, p. 27, pl. 3, fig. 1.

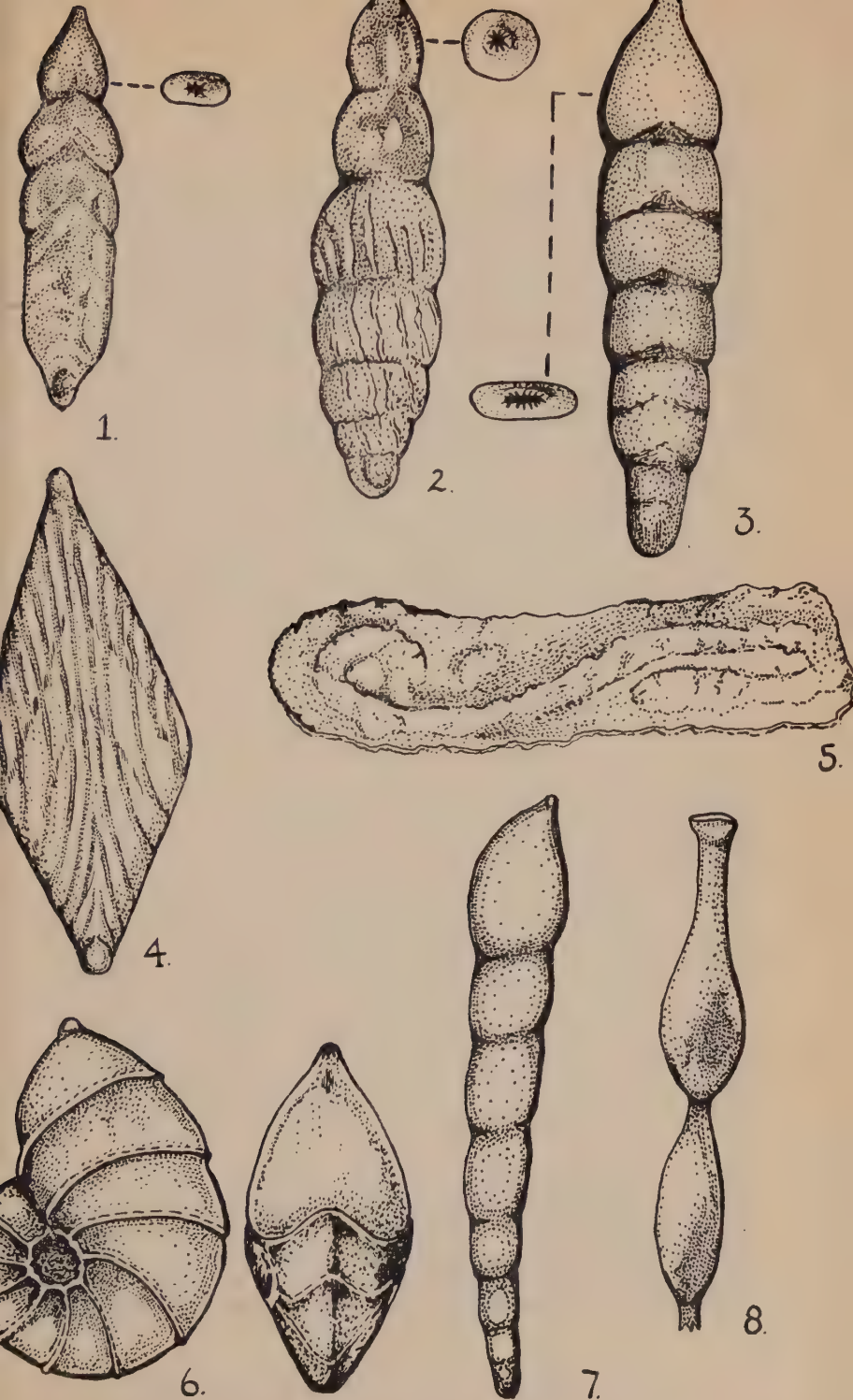


FIG. A.—Upper Oxford Clay Foraminifera from Warboys.

Description. The variable shape of the smooth test depends largely for its ultimate form on rapidly changing growth-rates. In cross-section the test is compressed and elliptical. After the first chambers the growth is usually regular, giving rise to an almost parallel-sided test. However, there often occur rapid changes, either sudden increases or decreases in the size of the chambers, so that the test appears to be made up of various sections with irregular chamber-widths. The initial apiculate globular proloculum is followed directly by a series of six to twelve slightly chevron-shaped chambers. Generally the sutures are flush with the surface of the test, but in some specimens there is a tendency for the sutures to be constricted in the later chambers. The radiate aperture is central and terminal.

Remarks. There is scarcely any visible difference between these specimens and those from the Lias, described by Terquem (1858) as *Frondicularia nitida* and by Bornemann (1854) as *Frondicularia brizaeformis*. The present author does not consider the specimens from the Oxford Clay to be derived directly from the Lias species, but that this is probably a further example of the recurrence of morphological types so common in the Lagenidae. This is a very common specimen throughout.

***Frondicularia pseudosulcata* sp. nov.**

Fig. A, 4 (P. 41175)

Diagnosis. The shape of the test varies from rhomboidal to elongate-rhomboidal. It is compressed, parallel-sided and consists of six to ten chambers. The microspheric form has a small globular initial proloculum, followed by two small chambers forming a short spire, and later by chevron-shaped chambers. The megalospheric form has no spiral portion. Immediately following a large globular or ellipsoidal proloculum, there is a linear series of chevron-shaped chambers. Specimens often show an apiculate proloculum. In some there is a rapid change in their otherwise regular growth, so that a series of smaller chambers are produced quite suddenly in the test.

Considerable variation is seen in the fine longitudinal costation. In the adult form there are between twenty-four and twenty-eight ribs. On most specimens the ribs can be divided into two regions, a central area bounded by two main costations with continuations of the coarse ribs extend around the edge of the proloculum, and areas external to this central region. The ribs on the central area, which tends to be arcuate, converge rapidly towards the aperture and are shorter towards the centre of the test. On later chambers straight ribs are added externally in relation to the central area, and these meet the former set at an acute angle. Some variants have almost parallel longitudinal costae, tending to curve downwards into the constrictions at the sutures, and are undifferentiated into two groups.

The central terminal, radiate aperture is often on an apertural chamberlet.

Holotype. In British Museum (Natural History) (P. 41175), taken at 10 ft. below Stone Band C.

Remarks. *Frondicularia pseudosulcata* sp. nov. differs from the Lias species, *F. dubia* Bornemann, in that the ribs are of equal strength, whereas, in the latter, the central two costae are much stronger than the others. It is a common species throughout the succession.

Genus: **SARACENELLA** Franke, 1936

Saracenella triquetra (Gümbel)

Fig. B, 2 ((P. 41181)

1862. *Cristellaria triquetra* Gümbel, p. 225, pl. 3, figs. 28a, b.

? 1935. *Cristellaria triquetra* Gümbel: Macfadyen, p. 16, pl. 1, figs. 19a, b.

Description. The test consists of a loosely coiled spire, composed of about seven chambers. The initial globular proloculum is followed by two or three chambers forming a small coil, and then by a curvilinear series. In cross-section the test is triangular, the sides of the triangle being almost straight. Slightly sunken sutures occur on the otherwise smooth test. Some specimens have the triangular shape emphasised by the appearance of 'keels' occurring at the angles of the triangle and continuing along the full length of the test. The radiate aperture is on an apertural neck. Forty-six specimens have been studied.

Remarks. The specimens described by Macfadyen (1935) are less triangular in cross-section than the forms described above and may represent a transition stage between the genera *Lenticulina* and *Saracenella*. These intermediate forms have been described by various authors as *Saracenaria*. Dealing with this problem Bartenstein (1948) separates the genus *Saracenella* from these intermediate forms, which are considered as a sub-genus of *Lenticulina*, and are designated *Lenticulina* (*Saracenaria*). The present author considers that the specimens from Warboys should be assigned to the genus *Saracenella*.

Genus: **PLANULARIA** DeFrance, 1824

Planularia protracta (Bornemann)

Fig. C, a-d (P. 41188)

1854. *Cristellaria protracta* Bornemann, p. 39, pl. 4, figs. 27a, b.

1865. *Cristellaria lanceolata* Schwager, p. 130, pl. 6, fig. 13.

1935. *Cristellaria protracta* Bornemann: Macfadyen, p. 15, pl. 1, figs. 17a, b.

Description. The test is comprised of a variable number of chambers arranged in a loose coil. The shape of the compressed and parallel-sided test varies from oval to triangular.

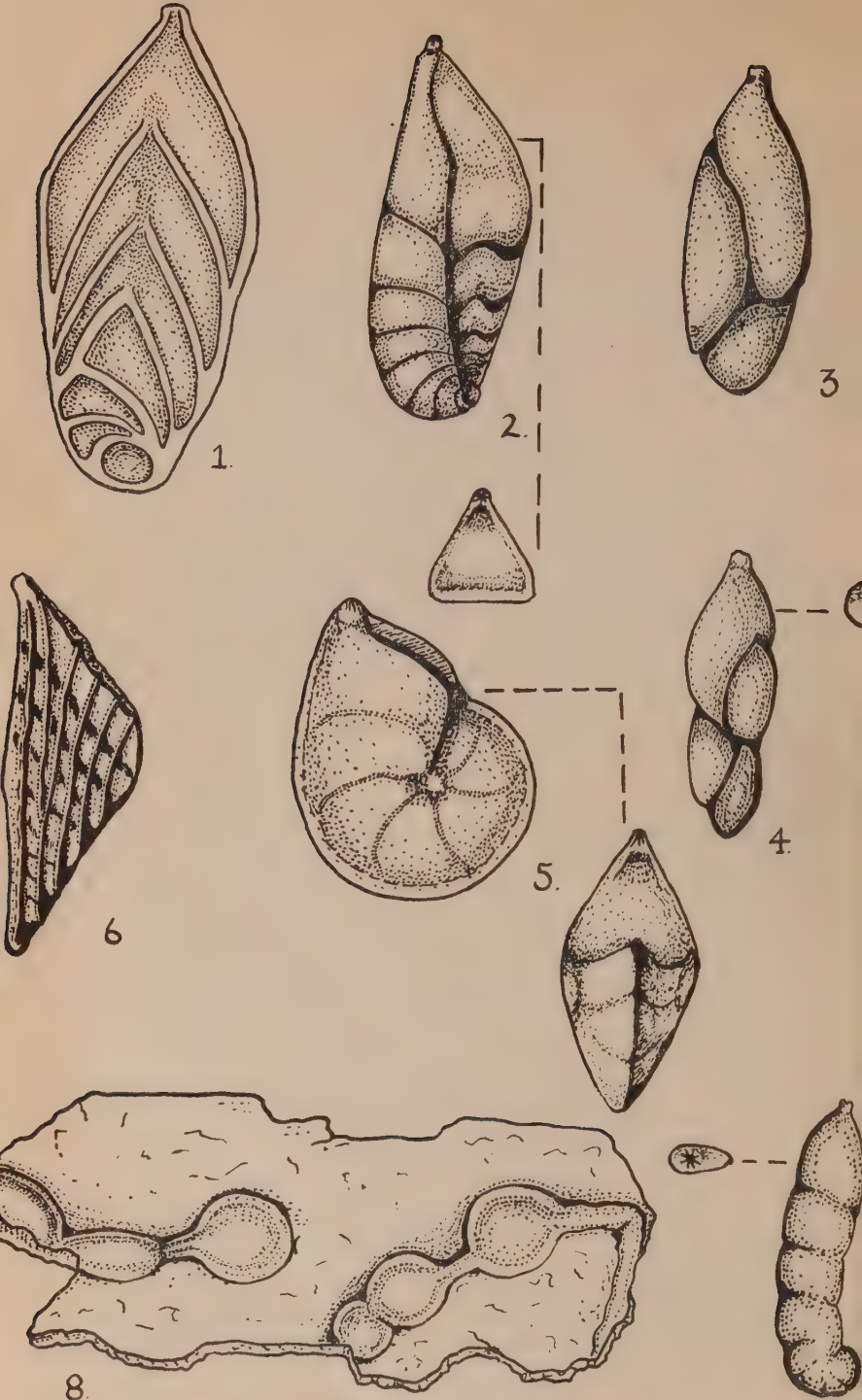


FIG. B.—Upper Oxford Clay Foraminifera from Warboys.

Variation—The variation in the shape of the test depends on the degree and amount of overlap of the chambers on the non-apertural margin, as well as the point where the overlap first begins. The chambers are usually triangular and taper towards the proloculum. The chief variants are seen in Fig. C.

Fig. C, a, shows two distinct growth-stages, the first with three chambers, showing no overlap on to the proloculum, and the second stage is similar but the dividing chamber shows a sudden increase in size and overlaps the earlier portion of the test on to the proloculum.

The final chamber is often smaller than the penultimate chamber.

Fig. C, b, shows the first three chambers overlapping on to the proloculum, then a stage is reached where no overlap occurs. This is comparable with Fig. C, d, a microspheric form.

Fig. C, c, shows the earlier chambers overlapping alternately.



FIG. C.—*Planularia protracta* (Bornemann) from Upper Oxford Clay, Warboys.

Remarks. There are a large number of described Jurassic 'species' which are similar in general shape, and, until there has been a comprehensive survey of these, it is desirable not to attempt a complete synonymy. The species is common throughout the succession.

Genus: **VAGINULINA** d'Orbigny, 1826

Vaginulina harpa Roemer

Fig B, 6 (P. 41184)

- 1841. *Vaginulina harpa* Roemer p. 96, pl. 15, fig. 13.
- 1842. *Vaginulina striatula* Roemer p. 273, pl. 6, fig. B, 2.
- 1851. *Vaginulina dunkeri* Koch, p. 172, pl. 24, figs. 5-7.
- 1904. *Vaginulina mosquensis* Uhlig: Bruckmann, p. 30, pl. 3, figs. 18, 19.

1921. *Cristellaria harpa* (Roemer): Klähn (*pars*), p. 61, pl. 4, figs. 8, 21, 26 only.
 1921. *Cristellaria mosquensis* (Uhlig): Klähn, p. 64, pl. 4, figs. 18–20, 22–24.
 1935. *Vaginulina harpa* Roemer: Macfadyen, p. 12, pl. 1, figs. 8a, b.

Description. The test is triangular in shape, elliptical in cross-section, and consists of a series of parallel-sided, or slightly tapering, chambers. An initial spiral portion occurred in only a few specimens. The ornament consists of about five coarse longitudinal costae on each side of the test. The radiate aperture is on a small apertural neck.

Remarks. These specimens, which occur sporadically, agree closely with those figured by Macfadyen (1935), and show little variation. The general shape, size and ornament are almost constant characters. Twenty-one specimens were studied.

Genus: **DENTALINA** d'Orbigny, 1826

Dentalina gümbeli Schwager

Fig. A, 7 (P. 41182)

1865. *Dentalina Gümbeli* Schwager, p. 101, pl. 2, fig. 20.
 1865. *Dentalina lutigena* Schwager, p. 102, pl. 2, fig. 22.
 1865. *Dentalina mutabilis* Schwager, p. 103, pl. 2, fig. 24.
 1886. *Dentalina Gümbeli* Schwager: Deecke, p. 20, pl. 1, fig. 14.

Description. The adult test consists of about nine smooth chambers arranged in a curvilinear series. The ellipsoidal proloculum is followed by a series of drum-shaped chambers, the sutures of which are slightly oblique. Later chambers are elongated and the sutures become constricted. A large amount of variation occurs in these specimens, both in the size of individuals, shape of chambers and in the amount of constriction at the suture.

Remarks. *Dentalina lutigena* Schwager (1865, pl. 2, fig. 22) is probably the figure of a young megalospheric specimen. It is highly probable that most, if not all, of the numerous species (33) described as new by Schwager (1865) represent variants of one or two species. There is little difference between the specimens from Warboys and the variable species *Dentalina pseudocommunis* Franke from the Lias. Twenty-seven specimens were studied.

Dentalina sp.

Fig. A, 8 (P. 41173)

Description. The only specimen found consists of two elongated, ellipsoidal chambers, drawn out into long tapering apertural necks. The aperture is circular, but this may be due to the resorption of a former radiate aperture.

Remarks. This specimen may represent the end-chambers of a *Nodosaria* but it closely resembles the figures of *Dentalina varians* Terquem (1866, p. 412, pl. 15, figs. 19 b, c only).

Genus: **NODOSARIA** Lamarck, 1812

? **Nodosaria** sp. (P. 41350)

Description. The test consists of six longitudinally striated chambers. The test of the only specimen found was compressed and may belong to the genus *Lingulina*.

Remarks. The specimen agrees closely with a form described and figured by Schwager (1866, p. 98, pl. 2, fig. 12) as *Nodosaria* sp.

Genus: **LINGULINA** d'Orbigny, 1826

Lingulina cf. *laevissima* (Terquem)

Fig. A, 3 (P. 41176)

1866. cf. *Fronicularia laevissima* Terquem, p. 481, pl. 19, figs. 19a, b.

1935. cf. *Fronicularia laevissima* Terquem: Macfadyen, p. 11, pl. 1, figs. 6a, b.

Description and Remarks. The specimens are rare and badly preserved, so that no trace of ornamentation is visible. The compressed, narrow test consists of about six chambers, the sutures of which tend to become chevron-shaped. The sutures are flush with the surface of the test on the earlier chambers but later they become constricted. The chambers soon reach a stabilised width, following the globular proloculum, so that the test is almost parallel-sided. The aperture is slit-like. Six specimens were studied.

Genus: **PSEUDOGLANDULINA** Cushman, 1929

Pseudoglandulina cf. *vulgata* (Bornemann)

? 1854. *Glandulina vulgata* Bornemann, p. 31, pl. 2, figs. 1a, b, 2.

Description. The test consists of a globular or ellipsoidal proloculum followed by five to ten drum-shaped chambers, the sutures of which are flush with the surface of the otherwise smooth test, or, in later chambers, become constricted. Some variation occurs in the last formed chambers, which often increase rapidly in height, so as to become distinctly nodosarine. The radiate aperture is central and terminal.

Remarks. The specimens appear to be similar to those recorded from various horizons of the Lias, and, until more knowledge is available regarding the Jurassic species of smooth *Pseudoglandulinae*, the author feels that a new specific name for these Oxford Clay forms is not at present justified. Sixteen specimens were studied.

Pseudoglandulina radiata sp. nov.

| Fig. A, 2 (P. 41178)

Diagnosis. The test consists of a uniserial row of chambers. Following a globular proloculum are two or three smooth drum-shaped chambers which form a cone. The sutures of this initial portion of the

test are flush with the surface. Although a further two or more chambers, spherical in shape and having constricted sutures, are added to the middle part of the test, there is still a progressive increase in the size of the chambers in this part. Finally, two or three chambers are added and these progressively decrease in diameter but increase in height. The sutures become constricted, the chambers smooth, so that a smooth nodosarine growth-stage is added. In the middle portion there are twenty to twenty-four longitudinal costae. The radiate aperture is central.

Holotype. In British Museum (Natural History) (P. 41178), taken at 10 ft. below Stone Band C.

Fifteen specimens were studied.

Family POLYMORPHINIDAE

Genus: **POLYMORPHINA** d'Orbigny, 1826

Polymorphina jurassica Gümbel

Fig. B, 3 (P. 41185)

- 1862. *Guttulina jurassica* Gümbel, p. 228, pl. 4, figs. 15a, b.
- ? 1865. *Globulina laevis* Schwager, p. 137, pl. 7, fig. 5.
- 1865. *Guttulina strumosa* Gümbel: Schwager, p. 137, pl. 7, fig. 9.
- 1865. *Polimorphina pigmaea* Schwager, p. 138, pl. 7, fig. 8.
- 1886. *Polymorphina oolithica* Terquem: Deecke, p. 37, pl. 1, fig. 29.

Description. The test consists of a small globular proloculum followed by two ellipsoidal chambers arranged on opposite sides of the vertical axis. Except for slight constriction at the sutures the test is smooth. The aperture is radiate and terminal.

Remarks. There appears to be little difference between this species and specimens described from the Lias as *Polymorphina liassica* Strickland. Twenty-six specimens were studied.

Polymorphina jurassica Gümbel var. **mutabilis** Schwager

Fig. B, 4 (P. 41180)

- 1865. *Polimorphina mutabilis* Schwager, p. 138, pl. 2, fig. 4 and pl. 7, figs. 12, 13.

Description. The initial portion of the test is identical with that of the species. Further chambers are added alternating about the vertical axis in a diametrically opposed position. The sutures of later chambers become more constricted and the chambers swollen. Ten specimens were studied.

Genus: **BULLOPORA** Quenstedt, 1856

Bullopore rostrata Quenstedt

Fig. B, 8 (P. 41179)

- 1858. *Bullopore rostrata* Quenstedt, p. 580, fig. 8.
- ? 1884. *Webbina crassa* Terquem: Deecke, p. 17, pl. 1, fig. 8.
- 1935. *Bullopore rostrata* Quenstedt: Macfadyen, p. 18, pl. 1, figs. 23, 24.

ZONE

LOWER

TABLE I.—Distribution of significant fol

Description. The adherent test is often milky-white in appearance, and consists of two distinct portions. The initial end consists of a hemispherical proloculum, followed by a rather thick tube of about one turn. This latter is almost of equal width until the distal end is reached. Here it tapers abruptly, and is joined to the other portion of the test by a constricted neck. A varying number of hemispherical-shaped chambers (one to nine) make up a rectilinear or slightly meandrine test. This species is very common throughout the succession.

5. CONCLUSION

Foraminifera occurred in all the samples studied, although in a few they are extremely rare, being represented by less than ten individuals. Generally there are fluctuations in the number of Foraminifera present in the samples. These bear no relationship to the character of the residues, which are fairly consistent throughout, except above Stone Band G, where the samples are sandy and the Foraminifera are very rare. Some fluctuations are rapid; for instance, a very abundant fauna is found in the sample from 8 ft. below Stone Band A, whereas, two inches beneath, Foraminifera are very rare. In samples occurring between Stone Bands D and F, and also in two parts of the section between Stone Bands B and C, Foraminifera are very abundant.

The long range species *Lenticulina quenstedti* (Gümbel), *Lenticulina münsteri* (Roemer) and *Bullopore rostrata* Quenstedt occur throughout and, except for a few sporadic samples, constitute the bulk of the microfauna. *Planularia protracta* (Bornemann), *Frondicularia pseudosulcata* sp. nov. and *Lingulina franconica* (Gümbel) are next in abundance. These species, although of somewhat sporadic occurrence at times, again occur throughout the whole range. The remaining Foraminifera are sporadic and generally rare, and no definite divisions can be based on their ranges.

In conclusion, however, it may be said that there are major differences between the foraminiferal fauna from these zones and others occurring in the Oxford Clay. Work proceeding at the moment may help to show whether these are facies differences or of fundamental importance in zoning.

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EXPLANATION OF FIGURES

FIG. A

1. *Frondicularia franconica* (Gümbel) $\times 70$. 10 ft. below Stone Band C. (P. 41177)
2. *Pseudoglandulina radiata* sp. nov. Holotype $\times 70$. 10 ft. below Stone Band C. (P. 41178)

3. *Lingulina* cf. *laevis* (Terquem) $\times$ 160. 11 ft. 4 in. below Stone Band C. (P. 41176)
4. *Fronicularia pseudosulcata* sp. nov. Holotype $\times$ 70. 10 ft. below Stone Band C. (P. 41175)
5. *Tolypammina* sp. $\times$ 30. 6 ft. below Stone Band C. (P. 41186)
6. *Lenticulina quenstedti* (Gümbel) $\times$ 60. 10 ft. below Stone Band C. (P. 41174)
7. *Dentalina gümbeli* Schwager $\times$ 60. 5 ft. 4 in. below Stone Band C. (P. 41182)
8. *Dentalina* sp. $\times$ 125. 5 ft. 4 in. below Stone Band A. (P. 41173)

FIG. B

1. *Neoflabellina deslongchampsii* (Terquem) $\times$ 110. 12 ft. 8 in. below Stone Band A. (P. 41187)
2. *Saracenella triquetra* (Gümbel) $\times$ 70. 2 ft. below Stone Band A. (P. 41181)
3. *Polymorphina jurassica* Gümbel $\times$ 70. 8 ft. below Stone Band A. (P. 41185)
4. *Polymorphina jurassica* Gümbel var. *mutabilis* Schwager $\times$ 60. 8 ft. 8 in. below Stone Band A. (P. 41180)
5. *Lenticulina münsteri* (Roemer) $\times$ 70. 8 ft. 8 in. below Stone Band C. (P. 41172)
6. *Vagulina harpa* Roemer $\times$ 70. 2 ft. below Stone Band C. (P. 41184)
7. *Lenticulina flaccida* (Schwager) $\times$ 65. 2 ft. below Stone Band C. (P. 41183)
8. *Bullopore rostrata* Quenstedt $\times$ 65. 4 ft. below Stone Band A. (P. 41179)

FIG. C

- a-d. *Planularia protracta* (Bornemann) $\times$ 70. 8 ft. 8 in. below Stone Band A. (P. 41188)
 (a, b, c. Megalospheric specimens; d. Microspheric specimen.)

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